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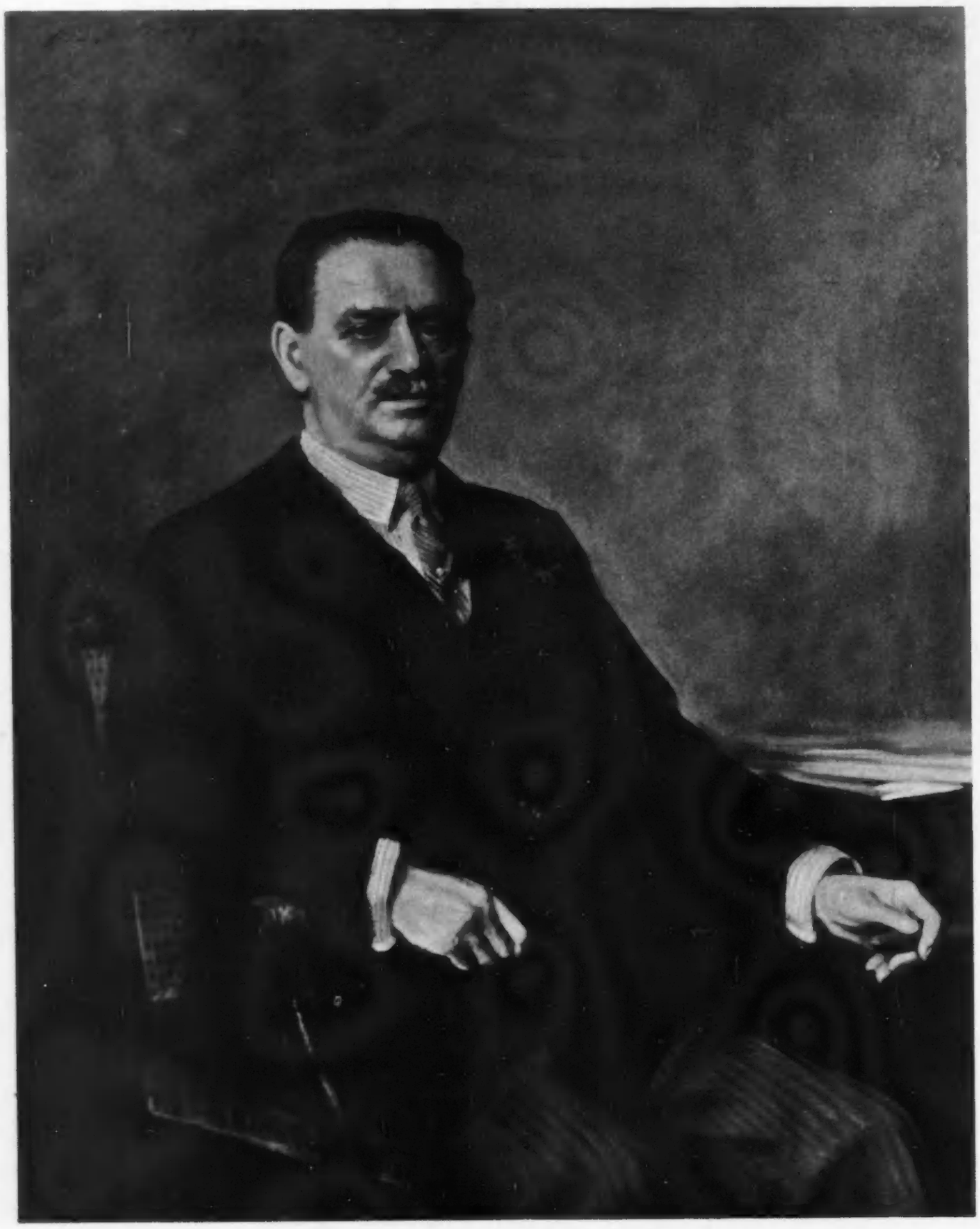

LORD HIRST OF WITTON.

Chairman and Managing Director of The General Electric Co., Ltd., who was elevated to the Peerage by His Majesty the King in the recent Birthday Honours.

From the original painting of Lord Hirst by Oswald Birley, R.A., which is hung in the Board Room at Magnet House, Kingsway.

G.E.C. Journal

VOL. V. AUGUST, 1934. No. 3.

Photometry of Coloured Light Sources.

WITH PARTICULAR REFERENCE TO ELECTRIC DISCHARGE LAMPS.

By G. T. WINCH, A.M.I.E.E., E. H. PALMER, B.Sc., C. F. MACHIN and B. P. DUDDING, A.R.C.S., F.Inst.P.

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In this article, the authors deal with the establishment of working standards and of reliable methods of making commercial photometric measurements on the new electric discharge lamps in terms of the international unit of candle power which is maintained in incandescent tungsten filament electric lamps. They show that photometric apparatus of the type which is satisfactory for comparing lights of closely similar colour, can, if used to measure these new light sources, give rise to extremely large errors (20 per cent to 100 per cent), the magnitude depending on the colour difference, the level of illumination and the characteristic of the observer's eye. On the other hand, it is shown that by using suitable methods, measurements can be made in a laboratory to a consistency of 3 per cent, and these methods are suitable for commercial application.

INTRODUCTION.

THE original British unit of candle power was the intensity of the light emitted by a sperm candle weighing 1/6th of a pound, burning at the rate of 120 grains of sperm per hour. This was accepted as the official standard in 1860. At a later date a lamp burning pentane vapour designed by A. Vernon Harcourt became the official standard of the Metropolitan Gas Referees. The intensity of the light in a direction at right angles to the flame of this lamp when burning under definite conditions of barometric pressure and humidity was found to be equal to that of 10 candles. Hence the official standard became the Pentane lamp giving 10 units of light.

In 1907, C. C. Paterson[1]* published a paper in which some large bulb, low voltage, incandescent carbon filament lamps were calibrated in terms of the pentane lamp. This was the beginning of a new era in which electric substandards were evaluated in terms of the British unit of light—the candle. In 1909, the same author[2] fore-shadowed international agreement with regard to the various standards of light. In this agreement the international candle became the fundamental unit and the values of the various national standards were expressed in terms of it.

In this comparison between carbon filament substandards and the pentane lamp a difference in colour existed between the light from the two sources which added to the uncertainty of making the photometric comparisons. In 1915, C. C. Paterson and B. P. Dudding[3] published data derived from work on tungsten filament substandard lamps. Six groups of lamps graded in temperature were utilized, series 1 emitting light of the same colour as the pentane lamp and series 6 emitting light of the same colour as the commercial tungsten filament lamp of that time. As the result of this work, electric substandards were obtained whose candle powers in a fixed direction were known in terms of the international candle. The authors showed in the same paper that the National Laboratories of France, America and Germany agreed with the values so determined to within 0.25 per cent. The introduction of the gasfilled lamp again raised the difficulty of the marked colour difference between the light emitted by the sub-standards of National Laboratories and commercial lamps, but in 1928 an agreement was established between the various National Laboratories.[4] The introduction of the high efficiency electric discharge lamp, the light from which differs in colour from that of the present day electric substandards by an amount greater than the difference between existing substandards and the pentane lamp, has raised the old problem in a more intense form than ever. During the next few years the National Laboratories will be striving to attain agreement in the value attributed to these newer light sources.

* For references see page 134.

It should be noted that the International candle is a unit of intensity, *i.e.*, a measure of the luminous flux in a given direction. During the past 15 years it has become more usual when rating lamps and estimating overall efficiencies of sources, to measure the total light output of a source rather than its intensity in a given direction. The total flux emitted by a source is measured in terms of a unit derived from the unit of candle power. This derived unit is the lumen and is the flux of light emitted in a unit solid angle by a source which has an intensity of one candle power in all directions. The total flux emitted by such a source is obviously 4π lumens, and this factor is the numerical relationship between the mean spherical candle power of a source and its output in lumens. In order to obtain the luminous output of a source, measurements of its candle power in all directions must be made and the mean spherical candles obtained by integrating these values. Owing to the small uncertainties of measurement introduced by this procedure it is clear that additional errors are likely to arise in the process of establishing the lumen unit from the unit of intensity—the candle.

Outputs of tungsten filament lamps can be measured to an absolute accuracy of about 0.5 per cent in a standardising laboratory, and this is the figure usually quoted on National Physical Laboratory reports.

From the earliest stages of the development of electric discharge lamps at the G.E.C. Research Laboratories, Wembley, it has been necessary to measure the luminous efficiency of these lamps. As already indicated, photometric comparisons of lamps emitting light of different colours had been mainly restricted to measurements of light emitted by incandescent bodies, *i.e.*, sources emitting a continuous spectrum. It has been well established that even with these small colour differences the results were seriously affected by the photometric field size, the photometer field brightness, the type of photometer used and the colour vision characteristic of the observer's eye.[5] During the past two years the photometric methods applied to the measurement of electric discharge lamps have been thoroughly investigated in the G.E.C. Research Laboratories and the work has played an important part in the development of these lamps. Recently, H. Buckley has published the results of investigations carried out simultaneously and independently at the Nation Physical Laboratory.[6]

Throughout this work photo-electric cells have only been used for the spectro-photometric determination of the transmission of the filters as their use enables greater speed and accuracy to be obtained with the existing spectro-photometric apparatus. Photo-electric cells have not been used for the general photometric work because the spectral response of the photo-electric cells at present available is such that, when comparing these coloured light sources, larger errors would occur than arise in the visual comparisons. The design of filters for use with the available photo-cells to modify their response to agree with that of the "average eye" entails a further programme of work which has already been started but which will take some considerable time to complete. This is a more difficult problem than that of comparing tungsten filament lamps operating at temperatures differing by two or three hundred degrees which has already been accomplished and has enabled measurements to be made at commercial speeds to an accuracy only previously associated with that of a standardising laboratory.[7]

2. EXPERIMENTAL PROGRAMME.

The methods of measuring sources of coloured light which have been investigated can be subdivided into two groups. The various types of photometer mentioned below were used for the reasons referred to in a previous paragraph in section 1.

(I) **The full colour difference between the tungsten standards and the coloured light source being present.**

(*a*) Using equality of brightness photometer with 2 degrees field.

(*b*) Using Lummer Brodhun contrast photometer with 6 degrees field.

(*c*) Using Guild flicker photometer with 2 degrees field.

(II) **The colour difference between the tungsten standards and the coloured light source being reduced to a minimum by the introduction of suitable filters.**

(*a*) Using equality of brightness photometer with 2 degrees field with filters calibrated spectro-photometrically and also by methods (Ia), (Ib) and (Ic) above.

(*b*) Using Lummer Brodhun contrast photometer with 6 degrees field with filters calibrated spectro-photometrically and also by methods (Ia), (Ib) and (Ic) above.

All the visual comparisons in the above two groups were made at a photometer field illumination of 25 metre candle or greater. This condition is generally agreed to be free from errors due to the Purkinje[8]* effect. However, measurements were also made at low illumination values in order to obtain estimates of the order of magnitude of the errors likely to arise by the various methods when making measurements in streets lighted by these coloured sources.

The spectro-photometric method of determining

* Purkinje showed that the colour sensitivity of the eye changes at low illuminations becoming more sensitive to blue light; large discrepencies can therefore arise when making photometric balances at low illuminations in presence of colour difference.

the transmission of a filter has been used in International comparisons of tungsten filament lamps against carbon substandards.[9]

3. PRELIMINARY EXPERIMENTS.

Before considering in detail the results of the photometric measurements made under the foregoing conditions, it is desirable to describe the procedure by which the results for the "average eye" are derived from the results of measurements made by a number of observers chosen at random.

(i). Y/B RATIO FOR ADJUSTMENT OF OBSERVER'S RESULTS.

This method of weighting the results obtained by individual observers according to the degree to which their colour vision departed from that of the "average eye," as defined by the relative luminosity data, is due to Ives.[10]

The colour response characteristics of the "average eye" are internationally agreed, and are given in a table in the Proceedings of I.C.I. Geneva 1924, p. 67.

Ives developed two filter solutions, one yellow and the other blue. These two filters are adjusted to have the same integral transmission to light of colour temperature 2077°K as measured by the hypothetical "average eye." The ratio of the transmissions of the two filters in this case would therefore be unity. However, in general, an observer does not make the ratio of the transmissions of these filters unity but some value usually between 0.8 and 1.2 for normal observers depending on the degree to which their colour vision departs from the normal.† This ratio will subsequently be referred to as the Y/B ratio of the observer.

The Guild flicker photometer operating at a field illumination of 25 metre candles, is recommended for making these measurements due to the greater certainty with which this photometer can be balanced in the presence of a colour difference.[11]

When measuring a source of light different in colour from that of the substandards, it will be found that individual observer's results plotted against their respective Y/B ratios will lie on a straight line. The slope of this line is related to the colour difference between the two radiations and is illustrated in fig. 1. In this figure are plotted the transmission values of seven filters measured by 15 observers on a Guild flicker photometer and Lummer Brodhun contrast photometer. These filters when used in front of a tungsten source modify its light in such a way that the transmitted light appears identical with that emitted by a source operating at a higher or lower temperature depending on whether the filter is blue or yellow. In fig. 2 the slopes of the Y/B lines have been plotted against the apparent difference in colour temperature introduced by the respective colour filters and it will be seen that the points lie about a straight line.

These measurements were included in this programme as a matter of general interest and because they embrace the range of similar determinations by Crittenden and Richtmyer.[12] The close

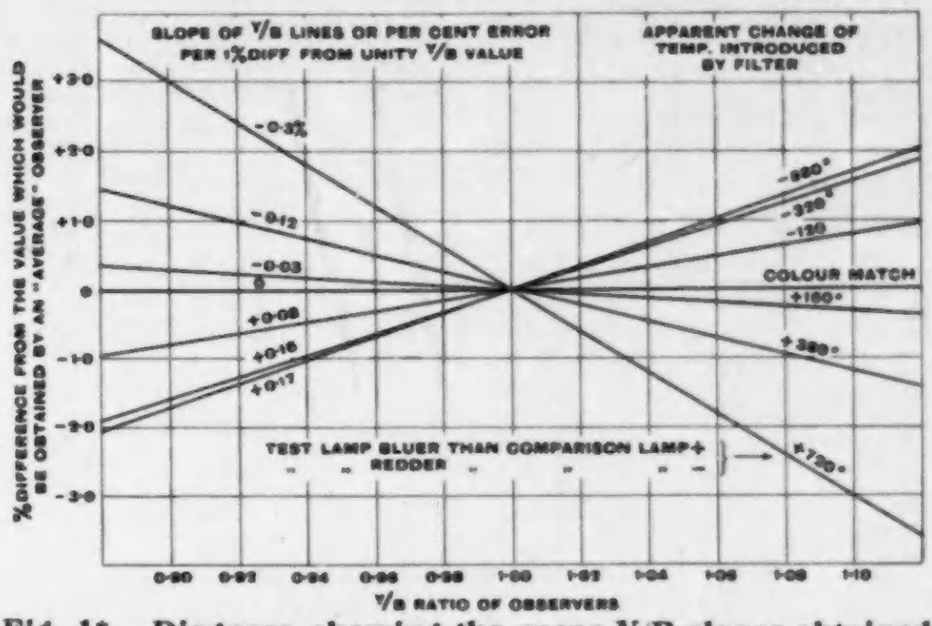

Fig. 1*.—Diagram showing the mean Y/B slopes obtained by Lummer Brodhun contrast (6° field) and Guild flicker photometer when measuring the transmissions of filters introducing apparent temperature differences between comparison and test lamps.

agreement with the results of the earlier investigators establishes confidence in the experimental procedure.

In cases like this where a definite relationship exists between the observations of individual observers and their respective Y/B ratios if the true value is assumed to be that indicated by the ordinate

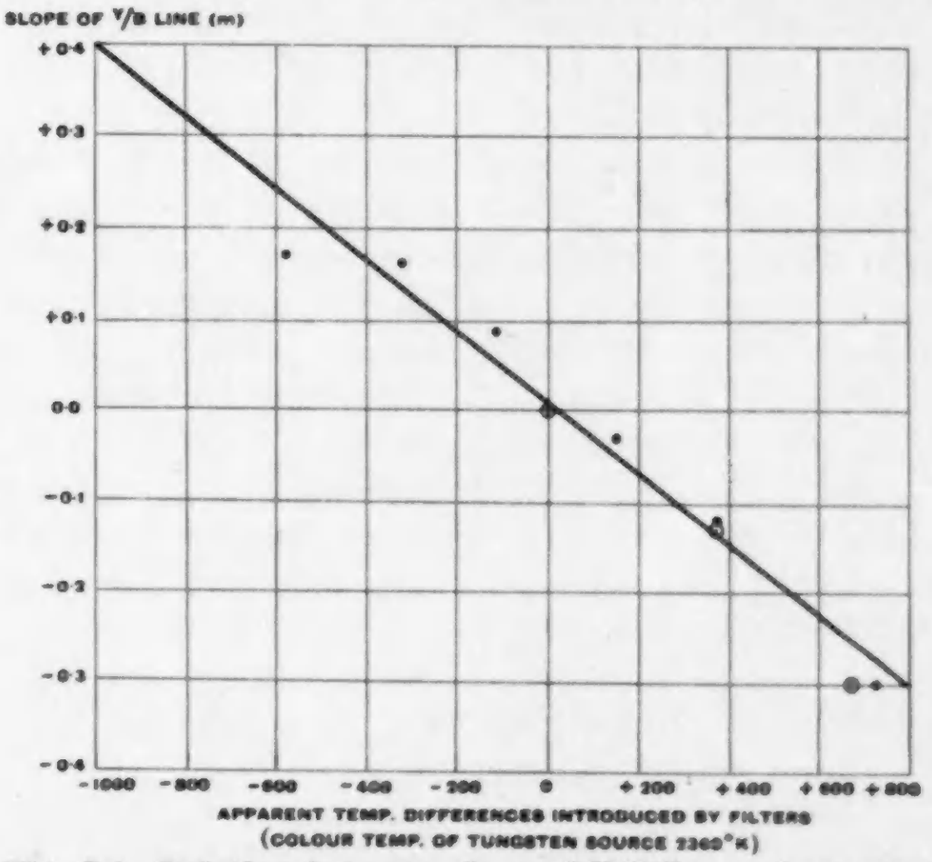

Fig. 2.*—Relation between slope of Y/B line and apparent temperature differences introduced by filters. The circles represent readings taken from scientific papers of Bureau of Standards No. 299, p. 110, by Crittenden and Richtmyer.

corresponding to the unity Y/B value, then any one observer's results can be corrected in the following manner.

If Y is candle power corresponding to the unity Y/B value, y the value obtained by an observer

† The differences here referred to are relatively small. They have no appreciable effect in all normal uses of the eye, and are far removed from a condition of colour blindness.

* Figs. 1 and 2 reproduced by kind permission of the Illuminating Engineer, July, 1934.

whose Y/B value is x and m the slope for the particular colour difference involved, then

$$Y = \frac{y}{1 + m\,(x-1.00)}$$

In the above equation the slope m of the Y/B line is the percentage change in candle power associated with a 1 per cent departure from the unity Y/B value.

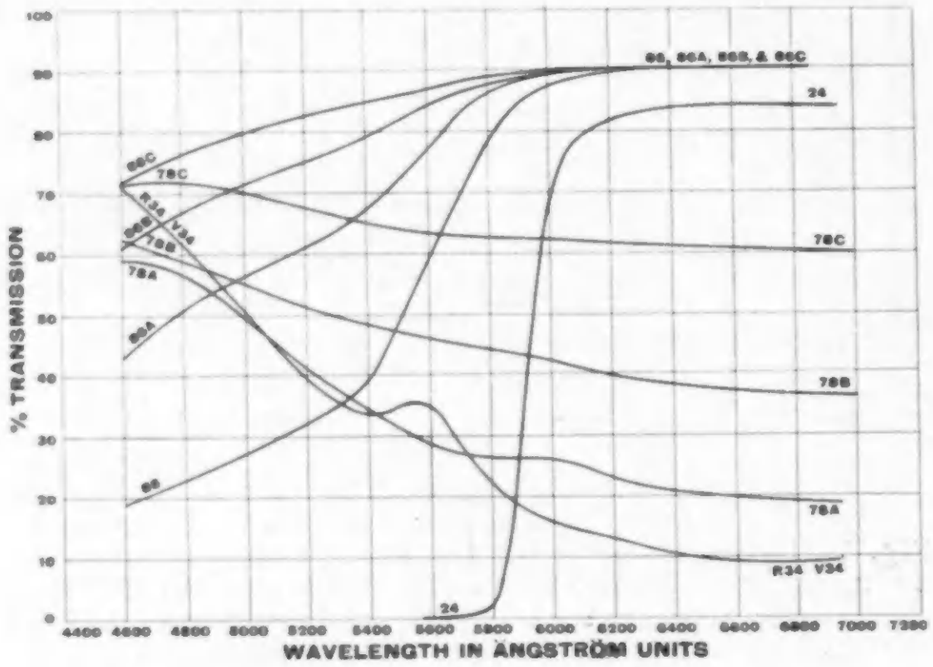

Fig. 3.—Transmissions of filters for equal energy.

Later in this article it is shown that the results of measurements on electric discharge lamps plotted in this way often exhibit a large spread calling for some method of calculating the best line through the points.

A detailed examination of the data obtained under conditions of full colour difference revealed the following facts :—

The average results obtained by all the observers when using the flicker photometer on different occasions are statistically consistent with their respective variations in the individual settings of the photometer on any one occasion. That is, there is no evidence of a systematic change in the observer's judgment on the different occasions.

With the other photometers however this is not the case and there is evidence that the majority of observers do not repeat their judgment from day to day to the same precision that they do on any one day. The differences are more marked with the equality of brightness than with the Lummer Brodhun contrast photometer.

These facts must be borne in mind if any attempt is made to utilize the Y/B correction to correct any observer's measurements obtained under the condition of large colour difference. Further it is the authors' opinion that for the large colour differences involved when measuring discharge lamps a larger number of observations than those detailed herein are necessary to determine the average correction to apply to the results obtained by any observer and that though this correction be determined to a higher precision, the magnitude of the residual error possible on any one occasion practically rules out the possibility of utilizing the contrast or equality of brightness photometer for these measurements.

(ii). MEASUREMENT OF TRANSMISSION FACTORS OF FILTERS.

Spectro-photometric method.

This method involves the measurement of the percentage of energy transmitted by the filter at every point throughout the visible spectrum. The results plotted as illustrated in fig. 3 are known as spectral transmission curves for equal energy.

In these measurements now described, the ratio was determined from the response of a photo-electric cell to the energy emitted by a substandard tungsten filament lamp at each point in the spectrum with and without the filter.

The percentage of light transmitted by the filter is estimated by integrating throughout the spectrum (1) the product of the transmission of the filter, the energy radiated by the source, and the

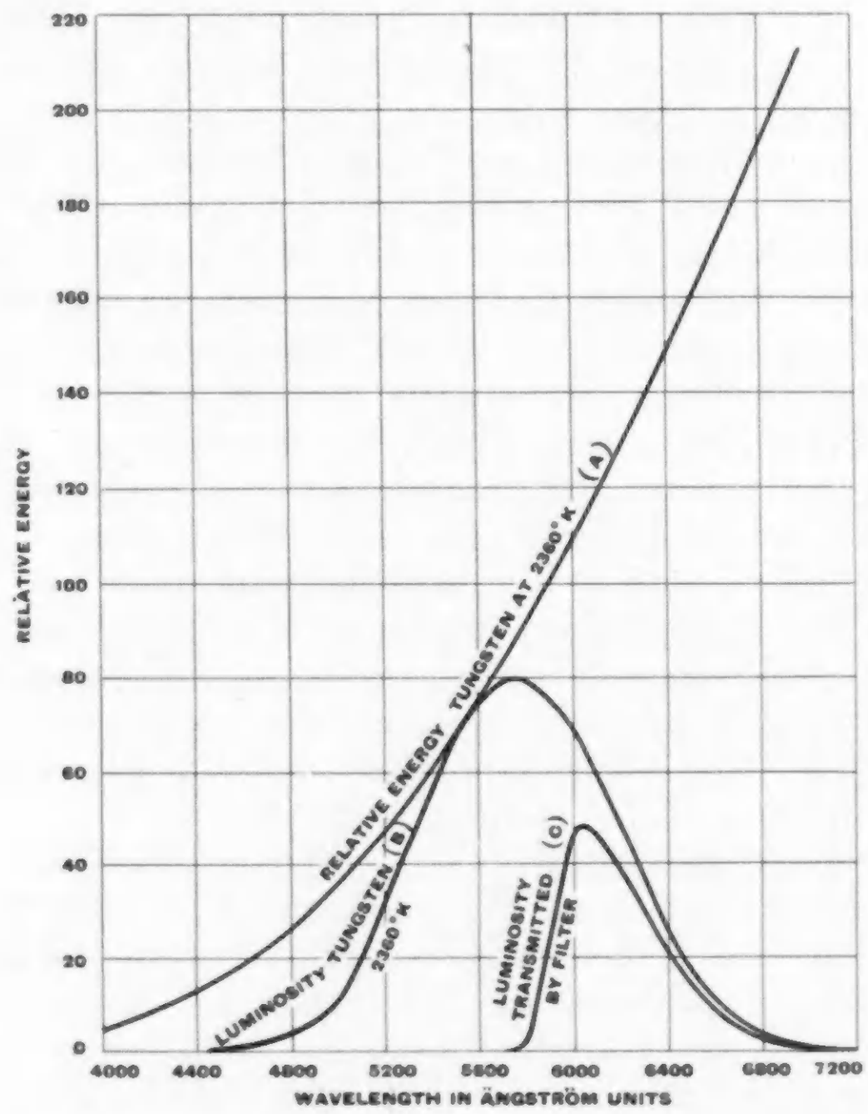
RELATIVE ENERGY
WAVELENGTH IN ÄNGSTRÖM UNITS
4000 4400 4800 5200 5600 6000 6400 6800 7200
0 20 40 60 80 100 120 140 160 180 200 220
RELATIVE ENERGY TUNGSTEN AT 2360° K (A)
LUMINOSITY TUNGSTEN (B) 2360° K
LUMINOSITY TRANSMITTED BY FILTER (C)

Fig. 4.—Spectral energy and luminosity curves.

relative luminosity data ;[13] and (2) the product of the energy radiated by the source and the relative luminosity factor. The transmission factor is the ratio of (1) to (2). This is illustrated in fig. 4 where curve A is the energy distribution curve for tungsten at 2,360°K, B the luminosity of the radiation and curve C the luminosity of the radiation (the light) transmitted by a filter. The area under curve C divided by the area under curve B is the transmission factor for radiation from tungsten at 2,360°K.

Expressed symbolically

$$\text{Transmission factor} = \frac{\int T_\lambda\, E_\lambda\, K_\lambda\, d\lambda}{\int E_\lambda\, K_\lambda\, d\lambda} \times 100$$

where T is the transmission of the filter at wavelength λ

E is the energy emitted by the source at wavelength λ

and K the relative luminosity of the energy at wavelength λ

The results of these measurements are given in Col. 4, Table I.

Because of the difficulties involved in these measurements two of the filters measured have since been calibrated by the National Physical Laboratory and the results are given in Table II., together with the measurements made by the authors for purposes of comparison.

Filter number R.34K34 suffered from imperfections which increased the difficulty of accurate measurement of its transmission and this accounts for the rather larger difference between the measurements in this case. The difference between the results of Wratten filter No. 24 is of the order expected.

TABLE I.

Col. (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
*Filter Number	Method of Measurement	Field Illumination Meter Candles	PerCent Transmission	Coefficient of Variation of Observations from Y/B Line	% Diff. of Unity Y/B Value from Spectral T'mission	Slope of Y/B Line	Largest % Individual Difference from Y/B Line
24	Spectro Photometer (Photo-electric) ..	—	29.4	—	—	—	—
	Flicker (Guild) 2° Field	25	28.0	4.8	—4.6	+1.87	10.6
Red	Lummer Brodhun Contrast 6° Field ..	25	25.6	11.1	—12.7	+2.50	18.8
	Equality of Brightness 2° Field	25	27.2	23.4	—7.2	+1.50	44.0
86	Spectro Photometer (Photo-Electric) ..	—	67.2	—	—	—	—
	Flicker (Guild) 2° Field	25	66.0	1.3	—1.8	+0.37	2.7
Yellow	Lummer Brodhun Contrast 6° Field ..	25	64.4	2.6	—4.2	+0.19	4.0
	Equality of Brightness 2° Field	25	61.9	9.1	—7.9	+0.23	15.5
86A	Spectro Photometer (Photo-Electric) ..	—	79.5	—	—	—	—
	Flicker (Guild) 2° Field	25	78.8	1.2	—1.0	+0.16	5.0
	Lummer Brodhun Contrast 6° Field ..	25	77.5	1.4	—2.5	+0.17	2.6
	Equality of Brightness 2° Field	25	73.9	4.8	—7.0	+0.61	11.5
86B	Spectro Photometer (Photo-Electric) ..	—	85.7	—	—	—	—
	Flicker (Guild) 2° Field	25	84.0	1.5	—2.0	+0.16	3.3
	Lummer Brodhun Contrast 6° Field ..	25	83.8	1.1	—2.2	+0.15	2.6
	Equality of Brightness 2° Field	25	82.6	4.3	—3.5	+0.04	9.1
86C	Spectro Photometer (Photo-Electric) ..	—	87.1	—	—	—	—
Light	Flicker (Guild) 2° Field	25	87.2	1.3	+0.1	+0.13	2.4
Yellow	Lummer Brodhun Contrast 6° Field ..	25	87.9	1.1	+1.0	+0.03	2.2
	Equality of Brightness 2° Field	25	88.4	2.7	+1.7	—0.45	7.3
78C	Spectro Photometer (Photo-Electric) ..	—	64.8	—	—	—	—
Light	Flicker (Guild) 2° Field	25	65.3	1.4	+0.8	+0.01	3.7
Blue	Lummer Brodhun Contrast 6° Field ..	25	66.4	0.6	+2.3	—0.08	1.2
	Equality of Brightness 2° Field	25	65.5	5.2	+1.1	+0.06	13.0
78B	Spectro Photometer (Photo-Electric) ..	—	44.4	—	—	—	—
	Flicker (Guild) 2° Field	25	45.8	1.4	+3.1	+0.01	3.3
	Lummer Brodhun Contrast 6° Field ..	25	47.2	1.1	+6.2	—0.24	2.2
	Equality of Brightness 2° Field	25	48.8	4.8	+10.0	—0.14	8.2
78A	Spectro Photometer (Photo-Electric) ..	—	29.6	—	—	—	—
	Flicker (Guild) 2° Field	25	29.5	1.3	—0.3	—0.14	2.9
Blue	Lummer Brodhun Contrast 6° Field ..	25	30.5	2.3	+3.0	—0.46	4.5
	Equality of Brightness 2° Field	25	32.2	12.9	+8.7	+0.17	29.0
R.34	Spectro Photometer (Photo-Electric) ..	—	25.7	—	—	—	—
K.34	Flicker (Guild) 2° Field	25	25.1	2.5	—2.3	—0.82	4.5
	Lummer Brodhun Contrast 6° Field ..	25	26.9	4.4	+4.7	—1.01	10.0
	Equality of Brightness 2° Field	25	26.6	4.8	+3.5	—0.17	10.6

* All these filters, with the exception of R.34, K.34 are Kodak Wratten Filters.

TABLE II.

Intercomparison of Spectro-Photometric Measurements on Colour Filters.

Type of Filter	No. of Filter	Temperature of Tungsten Source	Integral Transmissions		% Difference
			N.P.L.* value	G.E.C.†	
Red Filter No. 24	57792	2360°K	29.9	29.4	—1.7
Blue Filter	R.34 K.34	2600°K	24.8	25.7	+3.6‡

* See N.P.L. Report No. G.1466 of 14th May, 1934 for transmission values for equal energy throughout the spectrum

† The G.E.C. measurements were made before the filters were sent to the N.P.L.

In both cases the integral transmissions have been calculated in the manner described in the text, utilizing the spectral energy values for tungsten given in tables by J. F. Skogland.

(Miscellaneous publications of the Bureau of Stds. No. 86).

‡ Filter R.34, K.34 unstable (see text, Section 3 part (ii)).

Photometric method.

The measurement of the transmission of the filters by each of the three photometers—the equality of brightness, the Lummer Brodhun contrast and the Guild flicker—is accomplished in the following manner :—

A horizontal photometer bench is arranged with a comparison lamp at each end, both lamps operating at 2,360°K the colour temperature at which the

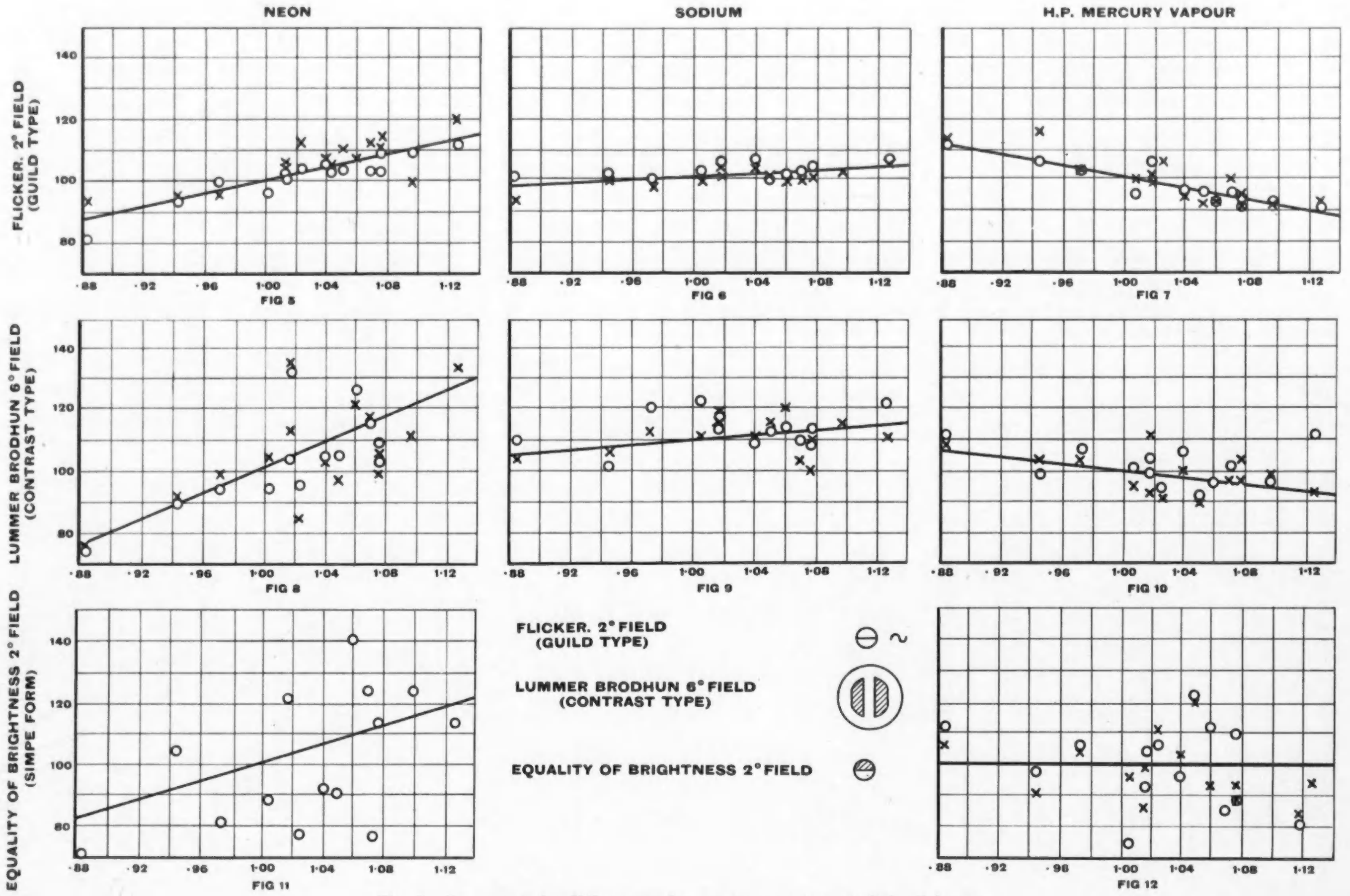

Fig. 5.—Representative Y/B curves for measurements on " Osira " lamps.

transmission of the filters is required. Photometric balances are made by each observer with and without the colour filters.

The ratio of the intensity measurements with and without the filter is the transmission of the filter as measured by the observer. In order to obtain the transmission values which would be determined by the hypothetical "average eye" the mean of six settings by each of 15 observers on one occasion is plotted against their respective Y/B ratios in the manner illustrated earlier in fig. 1. By the method of least squares a line was calculated through the points so plotted and the ordinate corresponding to the unity Y/B value is the required transmission.

All these measurements were repeated on another occasion and the mean of the transmission values so obtained are given in Col. 4, Table I.

It was found that when plotted against Y/B ratios the individual observers' mean transmission values under any one condition of colour difference departed from the line drawn through them to a smaller or greater extent depending on the type of photometer used. The coefficient of variation of the observations from the Y/B line has therefore been estimated in each case and provides a measure of the consistency of the respective methods. These values are given also in Col. 5.

Col. 6 shows the percentage difference of the transmission values obtained by each of the direct photometric methods from the values determined by the spectro-photometric method. It is interesting to note that these errors change progressively in magnitude and sign depending on the degree of colour difference introduced by the respective filters which are arranged in the table in order of their colours from red to blue.

Col. 7 gives the slope of the Y/B line in each case.

In considering these values of slope for the different photometers it is necessary to consider the figures in Col. 5 because when the value of the coefficient of variation is large there is greater uncertainty in the value ascribed to the slope of the Y/B line. It is clear, therefore, that the use of the slope of this line to correct individual observers' measurements would be liable to greater uncertainty the greater the value given in Col. 5.

Col. 8 shows the largest deviation from the Y/B line of a value obtained by one observer on two occasions (mean of six settings on each occasion). This therefore represents the order of error which can arise when making such measurements, by one observer even assuming that a correction has been applied corresponding to his Y/B ratio for the colour difference in question. These figures in Col. 8 only illustrate in another way the conclusions drawn from a study of the figures in Col. 5 as to the degree of uncertainty arising out of the use of the various photometers.

It remains to consider the values of the transmission factors given in Col. 4 and to decide what value shall be ascribed to each filter. Previous workers utilizing the three forms of visual photometer at high field brightness with relatively small colour differences have found that the flicker and equality of brightness 2° field photometers are in agreement but that the large field photometer yields somewhat different results. These investigations usually covered a smaller range of colour difference than that in Table I. It will be seen from Col. 6 that the results for filters 78C, 86B and 86C are in reasonable agreement whichever method is used, but as already pointed out the observations are least consistent when the equality of brightness photometer is used. For the whole range of colour difference here considered the spectro-photometer and the 2° field flicker photometer methods give consistent results. In the absence of international agreement as to which procedure is to be adopted when measuring these transmission factors the authors utilize the result derived by the spectro-photometric method.

It should be borne in mind that the luminosity data used in this method involves the use of a visual photometer of small field at high field brightnesses.

4. RESULTS.

(i). CANDLE POWER MEASUREMENTS ON ELECTRIC DISCHARGE LAMPS.

All the discharge lamps referred to in this article were "Osira" lamps made by the G.E.C. Before proceeding with the measurement of the candle power of the various types of discharge lamps, some preliminary measurements were first made to determine the suitability of such lamps as substandards.

The results obtained showed that in most cases they could be set up to a higher precision on D.C. than on A.C. because a battery supply could be utilized in the former case. Ageing measurements on the high pressure mercury vapour lamps showed that with the normal type of lamp which is designed for operation vertically cap up, the candle power fall, even under the most favourable conditions on D.C., is greater than on A.C. However, all the measurements in this work were made with the lamps operating on D.C. in order to avoid stroboscopic effects when using the flicker photometer. Care must be taken when operating the lamps on D.C. to ensure that the cathode is at the top or cap end as the candle power fall will be considerably greater if this precaution is not taken. Lamps from the same batch of manufacture were found to vary somewhat in their candle power performance and therefore as in the case of tungsten filament substandard lamps specimens had to be chosen for their suitability as reference lamps. In general it is found that changes in light output are accompanied

by changes in the electrical characteristics and, provided that for a given setting of amperes or volts across the lamp, the watts remain constant, the light output can be assumed not to have changed appreciably.

The rate of change of light output with the time when operating these lamps on D.C. was found to be sufficiently small to enable the selected lamps to be used for reference lamps for the duration of the various experimental measurements. Hot cathode neon discharge lamps were found to give consistent results but the sodium lamps were found to be less constant in candle power.

Candle power measurements have been made according to the programme set out in Section 2 using selected hot cathode electric discharge lamps of the neon, sodium and high pressure mercury vapour types.

It is not possible to reproduce in the paper all the Y/B curves which it has been necessary to plot in the course of this investigation, however in figs. 5 to 12 typical diagrams are shown. These diagrams clearly illustrate the difference in the results obtained for the three types of lamp measured by means of the three types of visual photometer against tungsten filament substandards in the presence of the full colour difference at approximately the same field brightness. This series of measurements will be seen to be similar to those made on filters. As in the case of the filter measurements, it will be seen that the individual results obtained with the flicker photometer are the most consistent and the equality of brightness the least. All the results are summarized in Table III. in a manner similar to that adopted in Table I. for the filter transmission data, the values given being the average of two independent determinations.

No direct determinations of candle power have yet been made by spectro-photometric methods. The flicker photometer result for each lamp is arbitrarily chosen as the reference standard in Table III. and in Col. 6 the differences from this standard are given. Again it should be noted that, as in the case of the filters, there is a progressive change in the sign and magnitude of these differences.

Considering the results given in Col. 4, Table III, it is clear that there is reasonable agreement between the three results obtained respectively with the flicker photometer (full colour difference), the Lummer Brodhun contrast and equality of brightness photometers (no colour difference-filter transmission determined by spectro-photometer). Large differences are introduced if the transmission factors of the filters derived by visual photometric methods are used. Hence reasonable concordance in the results can be obtained provided that filter transmission factors determined by methods other than the spectro-photometric method are ignored. Before

TABLE III.

Col. (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Type of Tube	Method of Measurement	Field Illumination Meter Candles	Candle Power	Coefficient of Variation of Observations from Y/B Line	% Diff. of Unity Y/B Value from Direct Result with Flicker Phot	Slope of Y/B Line	Largest % Difference from Y/B Line
Osira Neon	Flicker (Guild) 2° Field – – Full Colour Difference ..	25	83.5	2.9	—	+1.10	5.5
,,	Lummer Brodhun Contrast 6° Field ,, ,, ,, ..	25	74.5	11.3	—10.8	+2.20	27.3
,,	Equality of Brightness 2° Field ,, ,, ,, ..	25	78.0	22.2	— 7.2	+1.70	52.5
,,	Lummer Brodhun Contrast 6° Field Filter 24 Cal. by Spectro .	25	81.0	0.8	— 3.0	+0.03	2.0
,,	,, ,, ,, ,, ,, ,, ,, Flicker .	25	77.0	0.8	— 7.8	+0.03	2.0
,,	,, ,, ,, ,, ,, ,, ,, L.B. ..	25	70.7	0.8	—15.3	+0.03	2.0
,,	Equality of Brightness 2° Field ,, ,, ,, Spectro ..	25	79.3	1.2	— 5.0	—0.05	1.7
,,	,, ,, ,, ,, ,, ,, ,, Flicker ..	25	75.5	1.2	—10.5	—0.05	1.7
,,	,, ,, ,, ,, ,, ,, ,, L.B. ..	25	69.3	1.2	—18.6	—0.05	1.7
,,	Flicker (Guild) 2° Field – – Full Colour Difference ..	0.35	3.24	11.4	—	+0.80	23.8
,,	Lummer Brodhun Contrast 6° Field ,, ,, ,, ..	0.35	1.92	27.8	—40.6	+2.20	47.5
,,	,, ,, ,, ,, Filter 24 Cal. by Spectro .	0.35	2.74	1.6	—15.3	+0.07	2.7
,,	,, ,, ,, ,, ,, ,, ,, Flicker .	0.35	2.60	1.6	—19.7	+0.07	2.7
,,	,, ,, ,, ,, ,, ,, ,, L.B. ..	0.35	2.39	1.6	—26.2	+0.07	2.7
Osira Sodium	Flicker (Guild) 2° Field – – Full Colour Difference ..	130	5150	1.9	—	+0.24	3.6
	Lummer Brodhun Contrast 6° Field ,, ,, ,, ..	130	4390	4.3	— 5.0	+0.37	10.0
,,	,, ,, ,, ,, Filter 86 Cal. by Spectro ..	60	5260	2.2	+ 1.5	+0.01	4.1
,,	,, ,, ,, ,, ,, ,, ,, Flicker ..	60	5160	2.2	+ 0.6	+0.01	4.1
,,	,, ,, ,, ,, ,, ,, ,, L.B. ..	60	5040	2.2	— 2.1	+0.01	4.1
Osira H.P. Mercury Street Lighting Type	Flicker (Guild) 2° Field – – Full Colour Difference ..	100	940	2.8	—	—0.95	4.8
	Lummer Brodhun Contrast 6° Field ,, ,, ,, ..	100	980	3.0	+ 4.3	—0.56	5.7
	Equality of Brightness 2° Field ,, ,, ,, ..	100	970	5.9	+ 3.2	—0.40	9.5
	Lummer Brodhun Contrast 6° Field Filter R34 K34 Cal. by Spectro	100	945	2.1	+ 0.5	+0.04	3.3
	,, ,, ,, ,, ,, ,, ,, Flicker	100	920	2.1	— 2.1	+0.04	3.3
,,	,, ,, ,, ,, ,, ,, ,, L.B.	100	990	2.1	+ 5.3	+0.04	3.3
,,	Equality of Brightness 2° Field Filter ,, ,, Spectro	100	960	3.3	+ 2.1	0.00	4.0
,,	,, ,, ,, ,, ,, ,, ,, Flicker	100	935	3.3	— 0.5	0.00	4.0
,,	,, ,, ,, ,, ,, ,, ,, L.B.	100	1005	3.3	+ 6.9	0.00	4.0
,,	Lummer Brodhun Contrast 6° Field Full Colour Difference ..	25	1050	4.8	—	—0.39	8.3
,,	,, ,, ,, ,, Filter R34 K34 Cal. by Spectro	25	1000*	2.3	—	+0.13	4.0
,,	Lummer Brodhun Contrast 6° Field Full Colour Difference ..	10	1030	3.4	—	0.00	6.6
,,	,, ,, ,, ,, Filter R34 K34 Cal. by Spectro	10	1000*	1.6	—	+0.05	4.0
,,	Lummer Brodhun Contrast 6° Field Full Colour Difference ..	2	1050	3.4	—	—0.17	6.5
,,	,, ,, ,, ,, Filter R34 K34 Cal. by Spectro	2	1000*	1.8	—	+0.13	2.8
,,	Lummer Brodhun Contrast 6° Field Full Colour Difference ..	0.2	1260	8.0	—	+0.01	15.0
,,	,, ,, ,, ,, Filter R34 K34 Cal. by Spectro	0.2	1000*	8.8	—	+0.38	13.3

* These measurements were only made on an arbitrary scale and the result obtained with filters has been adjusted to 1000 for convenience of interpretation.

deciding finally what value shall be ascribed to the candle power of the lamps, a neon and an H.P. mercury vapour lamp were measured independently on several occasions by a number of observers and the results are given in Table IV. These later experiments demonstrate clearly the reproducibility of the results.

On general principles the results obtained in the absence of a colour difference using different photometers should be in agreement. Further as the flicker photometer has been used for determining the relative luminosity data the only criticism which can be urged against its use in this work is the magnitude of the colour difference involved. Consideration of the figures given in Table III. demonstrate that the value derived by the use of a Lummer Brodhun contrast photometer and a filter calibrated by the spectro-photometric method is a good compromise to adopt and does not differ by more than 3 per cent from the value obtained by any method worthy of consideration. Of course this conclusion is confined to measurements made at the high illumination values usual in work of this class.

(iv). ILLUMINATION MEASUREMENTS BY PORTABLE PHOTOMETER.

It is only under the best conditions that measurements of illumination with commercial portable photometers can be made to an accuracy better than plus or minus 5 per cent and in the case of low illumination (less than 0.1 ft. candle) it is scarcely possible to keep the errors below plus or minus 15 per cent. The foregoing discussion of laboratory measurements on discharge lamps shows clearly that using one observer errors as large as 100 per cent may possibly occur when measuring street illumination produced by discharge lamps. Referring to Col. 8 of Tables I. and III., a single observer may introduce errors of 30 to 50 per cent even when his results are corrected in accordance with his Y/B ratio for the light in question, utilizing equality of brightness and contrast photometers without a filter in front of the tungsten comparison lamp in the photometer. However, the tables show that if a filter chosen to produce a colour match[14] is calibrated by a standardising laboratory then measurements could be made to the degree of accuracy associated with the measurements of tungsten lamp illumination with the same instrument.

(v). MEASUREMENT OF LUMENS.

The total light output of a lamp can be measured either by the point to point method in which measurements of candle power are made at many angles around the lamp and the mean integrated value estimated, or by operating the lamp in a photometric integrator. The latter method has the advantage of simplicity as the brightness of a portion of the inside wall of the integrator screened from the direct light of the lamp is proportional to the mean spherical candles or lumens of the lamp. By a simple photometric arrangement this can be accomplished in one measurement and is therefore the method usually employed for commercial measurements.

The photometric integrator, which may be a sphere or cube, depends for its correct functioning on the interior surface being a perfectly diffusing non-selective reflecting surface.[15] There is little

TABLE IV.

Col. (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Type of Tube	Method of Measurement	No. of Observers	Candle Power	Coefficient of Variation of Observations from Y/B Line	% Diff. of Unity Y/B Value from Mean Result with Flicker Phot	Slope of Y/B Line	Largest % Individual Diff. from Y/B Line
Osira Neon	Flicker (Guild) 2° Field Full Colour Difference	15	86.0	4.5	+ 1.7	+0.95	11.0
,,	,, ,, ,, ,, ,,	16	84.0	3.3	— 0.5	+1.15	5.1
,,	,, ,, ,, ,, ,,	15	83.5	3.3	— 1.3	+0.90	9.3
,,	,, ,, ,, ,, ,,	6	84.0	2.8	— 0.5	+1.40	5.0
,,	,, ,, ,, ,, ,,	6	85.5	2.9	+ 1.1	+1.15	3.7
,,	Lummer Brodhun Contrast 6° Field Full Colour Difference	14	75.5	11.0	—10.8	+2.50	23.3
,,	,, ,, ,, ,, ,,	15	75.0	12.2	—11.4	+1.65	28.5
,,	,, ,, ,, ,, Filter 24 Cal. by Spectro	16	80.5	0.9	— 4.8	—0.10	1.7
,,	,, ,, ,, ,, ,, ,, ,,	15	81.0	0.9	— 4.2	—0.11	2.4
,,	,, ,, ,, ,, ,, ,, ,,	15	84.5	1.4	— 0.1	—0.01	2.5
Osira H.P. Mercury Vapour Lamp	Flicker (Guild) 2° Field Full Colour Difference	13	925	2.7	+ 2.2	—0.81	4.9
,,	,, ,, ,, ,, ,,	13	950	3.2	— 0.4	—0.98	6.9
,,	,, ,, ,, ,, ,,	13	965	3.5	— 2.0	—1.33	5.8
,,	Lummer Brodhun Contrast 6° Field Full Colour Difference	13	985	7.7	+ 4.1	—0.58	19.0
,,	,, ,, ,, ,, ,,	13	1000	5.9	+ 5.1	—0.80	14.5
,,	,, ,, ,, ,, ,,	13	1020	4.5	+ 1.8	—0.63	8.0
,,	Equality of Brightness 2° Field ,, ,,	13	1000	8.7	+ 5.7	—0.49	20.0
,,	,, ,, ,, ,, ,,	13	925	8.8	— 2.2	—0.41	16.0
,,	,, ,, ,, ,, ,,	13	1010	7.0	+ 6.8	—0.40	12.6
,,	Lummer Brodhun Contrast 6° Field Filter R34 K34 Cal. by Spectro	13	950	2.4	+ 0.4	+0.10	4.3
,,	,, ,, ,, ,, ,, ,, ,, ,,	13	940	2.1	— 0.6	+0.02	3.5
,,	,, ,, ,, ,, ,, ,, ,, ,,	13	935	2.9	— 1.2	—0.08	4.4
,,	Equality of Brightness 2° Field Filter ,, ,, ,,	13	970	4.7	+ 2.5	—0.18	8.3
,,	,, ,, ,, ,, ,, ,, ,, ,,	13	945	3.0	— 0.1	+0.23	5.0
,,	,, ,, ,, ,, ,, ,, ,, ,,	13	955	3.8	+ 0.9	+0.27	7.0

difficulty in obtaining a paint* which approximates sufficiently closely to this requirement to enable sources of continuous radiation, such as tungsten filament electric lamps operating at different temperatures, to be compared to a high order of accuracy. However, when comparing the light from tungsten standard lamps with that of discharge lamps it is clear that even when suitable methods of measurement of the candle power of such sources have been established, precautions should be taken to ensure that the integrator paint is sufficiently non-selective in its reflection properties to prevent appreciable errors arising from this cause. An approximate test of the order of the error likely to arise from this cause can be made by balancing the light from a tungsten lamp inside the integrating sphere against that from a comparison lamp operating at the same colour temperature outside the sphere. This experiment is then repeated but the observations are made with the colour filters placed in turn between the telescope of the photometer and the observer's eye. The filters used were those which were found to modify the light from tungsten lamps to match closely that from the respective electric discharge lamps. The difference between the balance points with and without the filters should not be more than 1 per cent. In the work here described the errors arising from selective reflectivity of the paint in the integrators were negligible. It is clear that this test only applied strictly to the case where the spectral energy transmission curve for the filter agrees with the spectral energy distribution for the discharge lamp. Lamps of the Osira mercury vapour street lighting type have however been measured by the point to point method to determine their mean spherical candles or lumens and the results obtained by this method have been found to agree to within 1 per cent of the values found by the measurements made in the 5 ft. diameter spherical integrating photometer to which the tests for paint selectivity have been applied. This difference is well within the accuracy of measurement and is an independent proof of the good quality of the integrator paint.

Lamps measured in an integrator in this manner have been measured independently by Prof. Pirani of Berlin and the National Physical Laboratory; the results are shown in Tables VA and VB.

* Zinc waite paint over Coverine as a foundation paint is used in these Laboratories.

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TABLE VA.

Intercomparison of Photometric Measurements on Osira H.P. Mercury Vapour Lamps.

No. of Lamp	AMPERES			VOLTS			WATTS			LUMENS			L/W		
	O.K.*	G.E.C.	% Diff.	O.K.*	G.E.C.	% Diff.	O.K.*	G.E.C.	% Diff.	O.K.*	G.E.C.	% Diff.	O.K.*	G.E.C.	% Diff.
R.128 A.33	2.66	2.70	+1.5	147.6	148.0	+0.3	393	400	+1.8	12,650	12,600	—0.4	32.2	31.5	—2.2

* Results of measurements made at the Laboratories of the Osram Konzern (Report No. 79/699, Berlin 13/12/33) and published here by kind permission of Prof. Pirani.

TABLE VB.

Lamp No.	AMPERES		VOLTS		WATTS		LUMENS				L/W			
							N.P.L.		G.E.C.)		N.P.L.		G.E.C.	
(1)	(2) N.P.L.	(3) G.E.C.	(4) N.P.L.	(5) G.E.C.	(6) N.P.L.	(7) G.E.C.	(8) Eq. Br. 2° Field	(9) L.B. 5° Field	(10) Guild Flicker 2° Field	(11) L.B. Contrast 6° Field	(12) Col. (8) Col. (6)	(13) Col. (9) Col. (6)	(14) Col. (10) Col. (7)	(15) Col. (11) Col. (7)
112a N.P.L. 1934 (R/0 A34)	3.10	3.10	128.9	128.1	399.6	397.1	17000	15900	16600	16300	42.5	39.8	41.8	41.0
112b N.P.L. 1934 (R/0 B34)	2.94	2.94	138.0	137.2	405.7	403.4	17900	16700	17200	16900	44.1	41.2	42.6	41.9
Means	3.02	3.02	133.5	132.7	402.6	400.3	17450	16300	16900	16600	43.3	40.5	42.2	41.5

G.E.C. measurements were made before the lamps went to N.P.L.

N.P.L. measurements in Cols. (8) and (9) made with minimum colour difference—(filters calibrated spectro-photometrically). N.P.L. lumen valves reported accurate to ± 4% (Ref. Photo. 322.9).

G.E.C. value Col. (10) made with full colour difference.

G.E.C. value Col. (11) made with minimum colour difference—filters calibrated spectro-photometrically.

Electrical Equipment for the British Grid.

PART IV.—COMMUNICATION EQUIPMENT.

By N. C. SMART,
G.E.C. Telephone Works.

This is the fourth of a series of articles describing the electrical equipment supplied by the G.E.C. to the Central Electricity Board.

It was originally intended to include in this article descriptions both of the communication and protective equipments supplied, but it has since been considered advisable to separate these two subjects and to deal with the protective gear in a fifth article which will appear in the November issue.

The three previous articles dealt with (1) *Outdoor Sub-Station Equipment* (2) *Towers, Transmission Lines and Cables, and* (3) *Metering Equipment, and appeared in Vol. IV, No. 4, Vol. V, Nos. 1 and 2 respectively.*

IN controlling the working of an interconnected power network of the capacity and complexity of any area of the grid, the provision of an adequate communication system is of prime importance. The type of communication system employed is governed chiefly by two factors —the facilities required and the types of intercommunication channels available. In order fully to understand the nature of the facilities required, it will be necessary to consider in a general manner the duties which the officer controlling the area will be called upon to perform. Primarily he must ensure that an adequate supply at the correct frequency and voltage is always available at every point of demand connected to the system. Owing to the nature of the organisation of the C.E.B. it is also necessary to arrange that the various generating stations supplying the grid each generate their due share of current, and that the wattless component is also shared equitably among them. Basically the duties of the control engineer will therefore be :—

(*a*) To control the opening and closing of circuit breakers at each grid sub-station.

(*b*) To control the output from each generating station connected to the grid.

(*c*) To control the ratios of the transformers connecting the grid to the generating and consuming stations.

As control engineers are continuously on duty at each generating station, and as they have direct control over the operation of circuit breakers and transformers in the grid sub-stations, the central control engineer fundamentally requires only telephone

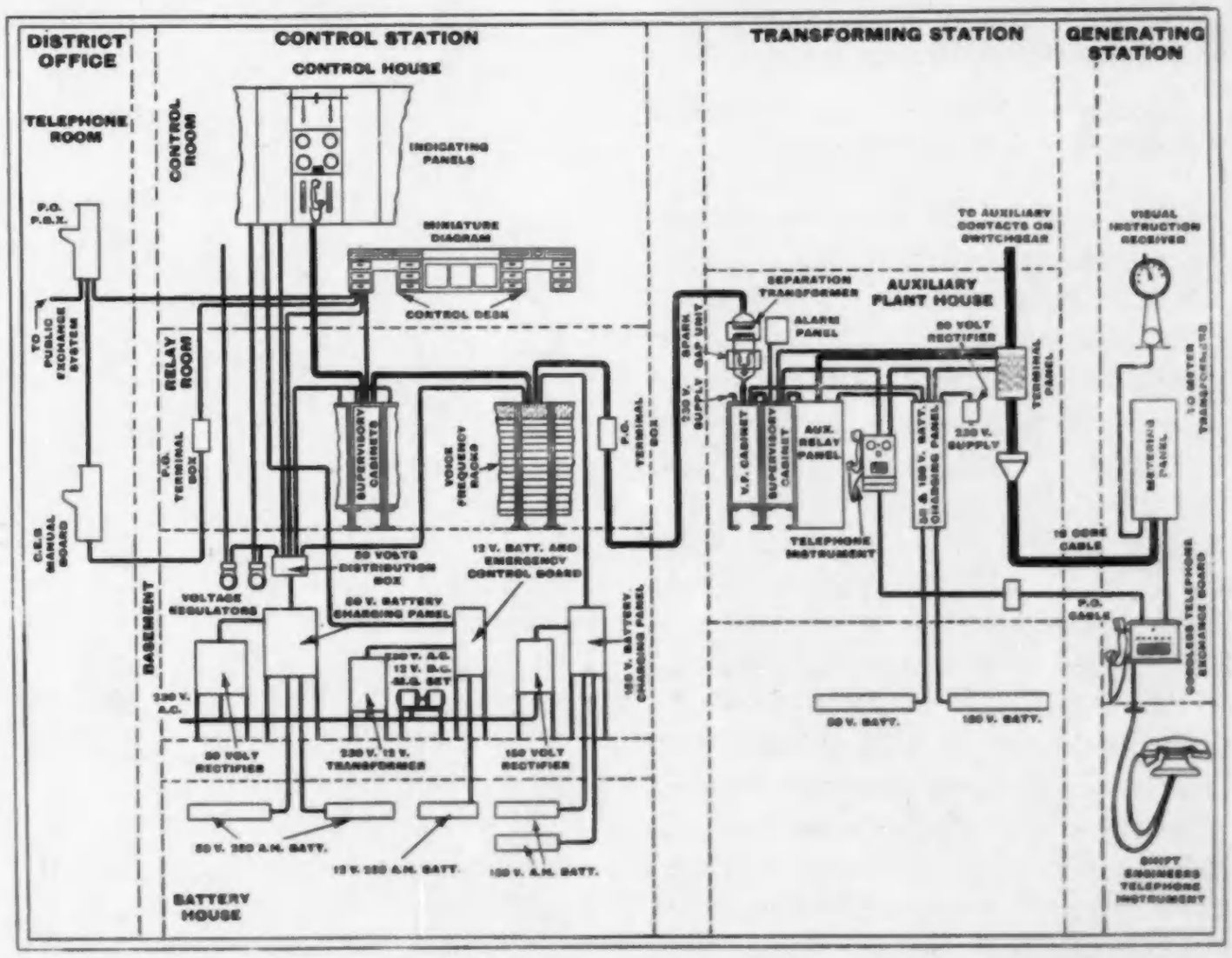


Fig. 1.—Diagram, left half of which shows layout of equipment and cabling at Central Control Station, Wake Green Road, Birmingham; right half showing equipment and cabling at a typical generating and transforming station.

communication with each of these stations to enable him to pass instructions to these control engineers, and to receive from them information concerning the position of circuit breakers, position of transformer tap changing switches and the readings of meters. It will be realised however that telephone

Fig. 2.—Central metering panel and visual instruction receiver at Hams Hall generating station.

communication alone has several disadvantages. First, there is a danger of errors in transmission and reception of telephone messages. Secondly, the time taken to receive and log information initiated simultaneously by several stations would render difficult the keeping of a reliable record of simultaneous conditions existing at all stations, particularly during periods of power line fault.

Further, to repeat periodical meter readings by telephone from each generating station would require a considerable amount of work and time on the part of both the local and central control staff.

From these considerations it will be seen that while the various control functions can be performed by the local staff acting upon telephone instructions from central control, indications of the conditions at all generating stations are not so readily obtainable and it becomes apparent that the communication system required is primarily a telephone system on which is superimposed a remote supervisory system giving continuous and accurate automatic indications of conditions throughout the area to central control. Such a system has been supplied in each grid area.

The choice of a suitable communication channel to each station involves the consideration of many diverse and complex factors. The types of channels available are generally :

(*a*) The ordinary national telephone service.
(*b*) Privately owned underground pilot cables.
(*c*) Privately owned pilot cables suspended from the power line supports.
(*d*) Carrier channels provided over the power cables.
(*e*) Private pilots rented from the national telephone administration.

Owing to the nature of facilities required and the possible delay in establishing connection (*a*) is entirely impracticable in the case under consideration. The cost of laying down underground cable rules out (*b*) on economic grounds. To provide the necessary separate channels to each station on a ring main would entail using a pilot cable of considerable size and this, if supported from the towers carrying the power cable, would entail an extra load on these towers and indeed would entail a considerable modification of their design: on this score scheme (*c*) is also ruled out. Of the two remaining methods (*d*) and (*e*), the C.E.B. have

Fig. 3.—Cordless telephone switchboard, installed at each generating station.

chosen the latter. When these communication systems were first decided upon, carrier signalling over power lines was in its infancy and the Board did not consider it advisable at that time to make use of such channels.

Pilot wires are rented from the Post Office, one separate pair from the central control room to each sub-station. The pairs are part of the Post Office telephone cable network, and are designed to transmit speech currents, that is alternating currents within a frequency band of approximately 200 cycles to

1,800 cycles per second. It cannot be guaranteed that the channel provided will consist of a continuous metallic circuit, as it may contain thermionic valve repeating stations, designed to amplify currents in the speech frequency range, also impedance matching transformers or other devices intended to deal only with speech currents. It will be appreciated that these factors make it necessary to use a system of line signalling which employs alternating currents of a frequency and amplitude of the order of speech currents.

Again, since the channels form part of the main P.O. telephone cable network, it is necessary to ensure that no high voltages can be applied to them. As the lines have to transmit meter readings from the generating stations, and as such readings must be obtained from instrument transformers in circuits of, say, 11 kV to 66 kV, there is a possibility that in the event of a breakdown in such a transformer, a voltage of a dangerous value might be applied to the Post Office lines. Special protective devices must therefore be inserted between the terminal equipment and the P.O. line.

Summarising the above, the communication system supplied in each area consists of :—

(*a*) A telephone service from the central control station to each generating station and transformer station in the area.

(*b*) An automatic supervisory system indicating continuously to the central control officer the condition of all circuit breakers and transformer tap changing switches in the area.

Fig. 4.—Voice frequency and supervisory apparatus cabinets (doors removed) at Nechells transforming station.

(*c*) A remote metering system which repeats at the central control the readings of certain meters at the generating stations and transformer stations.

The common communication channel employed for the whole of the above services consists of a

Fig. 5.—Rear view of apparatus cabinets at Ocker Hill (doors removed).

separate pair of telephone wires from the central control station to each generating station and transformer station, these wires being rented from the Post Office, and equipped with special protection devices to prevent dangerous voltages reaching the Post Office wires.

The communication system in the Central England Area, which may be considered typical, is described in detail in the following pages. The consulting engineers for this area were Highfield and Roger Smith.

CENTRAL ENGLAND EQUIPMENT.

The Central England area is controlled from a central control room in a building adjacent to the C.E.B. district office in Birmingham. Communication is provided with the following stations :—

Stoke	Nechells	Loughborough
Stafford	Hams Hall	Leicester
Ironbridge	Burton	Coventry
Bartley Green	Derby	Warwick
Worcester	Spondon	Northampton
Stourport	Nottingham	Kettering
		Ocker Hill

In addition, telephone communication only may be extended to the central control rooms of the South East England area at Bankside, the South West England area at Bristol and the North West area at Manchester.

A map of the Central England area appeared in the first article of this series (Vol. 4, No. 4, Page 243). In fig. 1 are shown the various elements making up the equipment of the central control station, and a layout which is typical of the supervisory equipment provided at each generating and transforming station.

In the control room of each generating station is a metering panel, fig. 2, which carries a number of Midworth transmitting megawatt meters together with a group of relays whose function is to change over the pressure connections of these meters when it is required to read megavars. In fig. 2 the meters on the two lower panels transmit the megawatt or megavar readings on the two feeders from the C.E.B. transforming station, and are operated from

Fig. 6.—Auxiliary relay and metering panel at Hams Hall transforming station.

the current and potential transformers used for the main metering equipment. The third meter is periodically set by hand to indicate and transmit the total load which the station is generating. The output from these meters is not transmitted directly to the central control but only to the auxiliary plant house in the associated C.E.B. transforming station which may be some distance away.

Also in the generating station control room is an instruction receiver shown in fig. 2. This forms an adjunct to the telephone service and enables seven stereotyped signals to be transmitted from central control to each generating station and gives central control an indication of the acknowledgment of each signal transmitted. It will be seen that the receiver takes the form of a standard engine room telegraph.

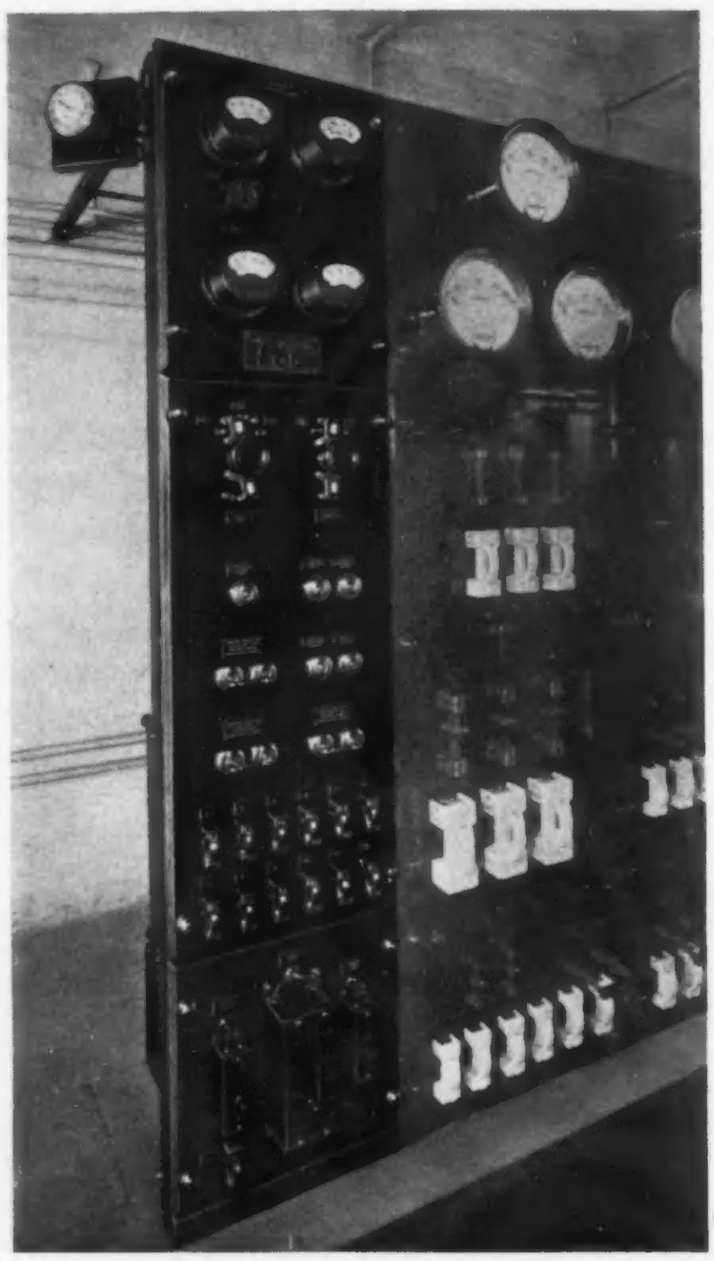


Fig. 7.—Typical sub-station supervisory battery charging panel.

A small telephone exchange board (fig. 3) is also accommodated in the generating station control room where the local control engineer acts as operator. Calls are received here direct from central control and connections established between the auxiliary plant house, the control engineer's office and central control.

AUXILIARY PLANT HOUSE.

The Post Office lines terminate in this building at the special protective devices previously mentioned. These consist of a line transformer (see fig. 1) designed to withstand a pressure of 15,000 volts between primary and secondary windings, and two spark gaps, set to flash over at 500 volts. The line is then connected to a voice frequency signalling cabinet and then to a supervisory equipment cabinet. Typical front and rear views of these cabinets are

Fig. 8.—Voice frequency signalling apparatus racks at Central Control, Birmingham.

shown in figs. 4 and 5. The supervisory cabinet is connected to an auxiliary relay and metering panel, an example of which is seen in fig. 6. This panel carries Midworth power-driven receivers (shown at the bottom of fig. 6) which accept the signals from the Midworth transmitters in the generating station and convert them into a form suitable for transmission over the supervisory system. There is one power-driven receiver for each transmitter. Also mounted on this panel in certain stations is the voltmeter transmitter, which signals to central control the 132 kV system voltage. As in this case the operating supply is derived from a potential coupler in the outdoor sub-station itself, it is not necessary to have separate transmitters and power-driven receivers and the two instruments are in effect combined in one.

Each circuit breaker in the transforming station has associated with it a relay which is operated by auxiliary contacts on the breaker and thus is caused to represent continuously the condition of the breaker. This relay is equipped with the necessary contacts to initiate and control signalling over the Post Office line, thereby indicating continuously at central control the condition of the breaker. The relays, mounted in individual cases, may be seen on the upper portion of the auxiliary relay panel in fig. 6.

Also mounted in the auxiliary plant house is a battery charging panel and rectifier (fig. 7) for charging the 50v and 150v batteries, which are accommodated in the station battery room.

A telephone instrument is mounted on the wall adjacent to the cabinets. This instrument may be used for communication with either central control or the local generating station.

CENTRAL CONTROL.

At the central control station the Post Office lines terminate in the relay room where they are connected directly to voice frequency signalling equipment which is arranged on a series of racks as shown in fig. 8. These are connected to a series of supervisory equipment cabinets, one for each station (fig. 9).

Each of these cabinets is wired to one section of the main indicating board in the control room. The arrangement of a typical section is shown in fig. 10. The lower panel of each section carries two tap-changing switch position indicators, each consisting of a strip of 15 lamps behind a stencil plate carrying the tap numbers. The particular lamp glowing indicates the tap in use.

The middle panel of each section carries the indicating meters which are automatically maintained in agreement with the initiating meters in the associated generating station. Also mounted on this panel is the visual instruction indicator, which records the last visual instruction sent to that particular generating station.

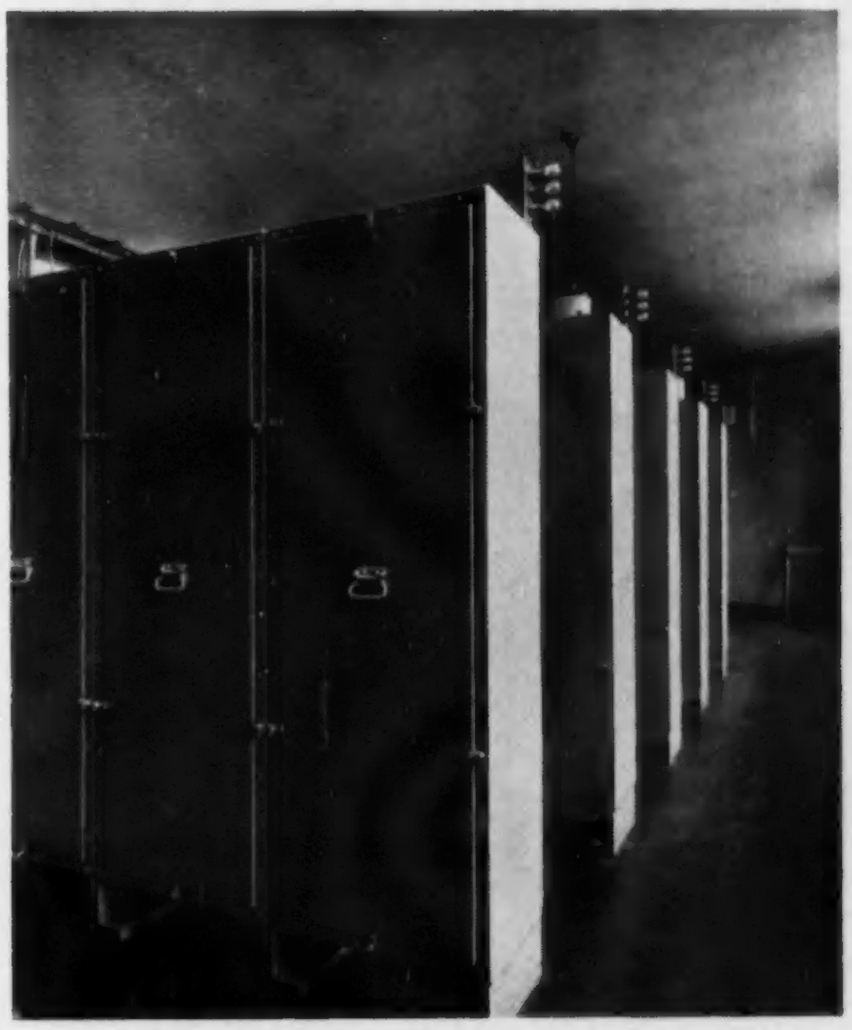


Fig. 9.—Supervisory apparatus cabinets at Central Control, Birmingham.

The top panel of the section forms a simplified single line diagram of the station. At the relevant points in the diagram appear the indicating lamps for the circuit breakers, each breaker being represented by three lamps, one red, one green, one white. The glowing of either the red or the green lamp indicates the condition of the circuit breaker, closed

or open, while the white lamp glows on the reception of a signal indicating a change in the condition of the breaker.

The centre section of this board forms a frequency indicating panel for the whole system and carries an indicating frequency meter, an integrating frequency meter controlled by a master pendulum clock in the control engineer's office, and a frequency recorder.

A view showing the complete indicating board is given in fig. 11. This also shows the control desk suite, consisting of two control officers' desks and a miniature diagram desk. The control officers' desks are identical and carry key and lamp turrets at the rear. The left hand section of each turret is equipped with keys and lamps which enable the officer to establish telephone calls to and from each

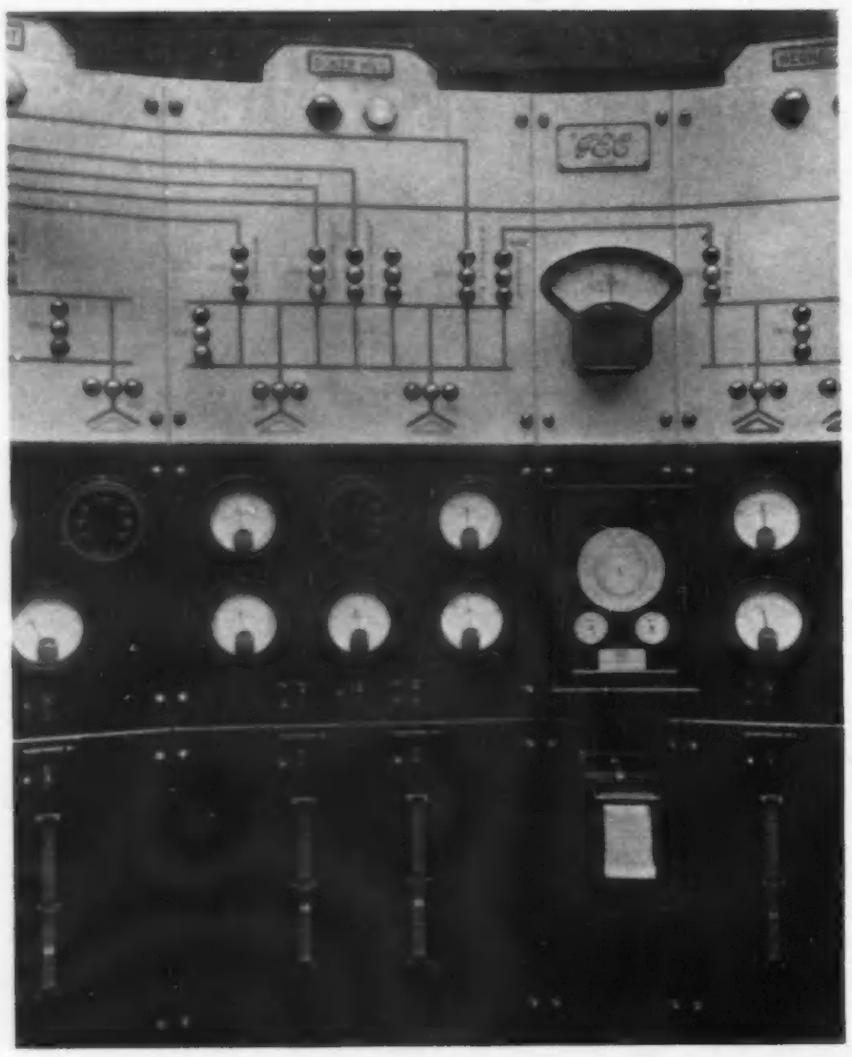


Fig. 10.—Section of main indicating board at Central Control.

generating station, or to transfer such calls to an operator for extension to the various offices. Calls can also be made, via the operator, to the ordinary post office system.

The centre section of the turret houses a common instruction transmitter. This is a miniature form of engine room telegraph and can be associated with any generating station by operation of one of the keys shown on the right hand section of the desk turret.

The surface of the miniature diagram desk carries a single line diagram of the whole system in more detail than is shown on the top section of the main board. In the relevant positions in this diagram are rotary hand-operated indicators representing all circuit breakers and isolators. A view of the diagram is given in fig. 12.

In the basement below the control room are three battery charging and control boards shown in fig. 13. The board on the right of this view controls the 12 volt battery used for the lamp indications on the main indicating board. Next to the panel is the 230 volt/50 volt transformer and rectifier unit and the associated 50 volt battery charging and control panel. The 230 volt/150 volt transformer and rectifier unit and the associated 150 volt battery charging and control panel are on the extreme left. All the cabling for the indicating board, the desk suite, and the relay room equipment, is run in the basement. The various cable runways are shown in the general view of the basement fig. 14.

DISTRICT OFFICE.

In the telephone exchange room in the district office adjacent to the control house is a Post Office private manual exchange board with lines to the nearest Post Office main exchange and to the various offices in the building. Adjacent to this is a small manual board which deals with the lines to the C.E.B. sub-stations. In fig. 15 the Post Office board is on the left and the sub-station board on the right.

Each sub-station line terminates on a jack and visual signal. Eight cord circuits are provided and two tie lines across to the Post Office board. Calls from the sub-stations to offices in the building are extended from the sub-station board by means of one of the cord circuits and one of the tie lines to the Post Office board where they are dealt with in the usual way.

Having outlined the layout of the equipment, the progress of various signals through the system may now be described in some detail.

CIRCUIT BREAKER TRIP SIGNAL.

When a circuit breaker trips, due to the action, say, of a protection relay, the changing over of the auxiliary contacts on the breaker will cause the associated relay on the auxiliary relay panel (fig. 6) to change over to the "tripped" position. In the supervisory cabinet a similar relay is associated with each circuit breaker and is held in a condition to agree with the indication appearing on the main indicating board at central control. Owing to the tripping of the breaker in the case under consideration there will now be a disagreement between the conditions of these two relays. This disagreement causes two signals to be sent to the central control station over the Post Office line. The first signal represents the type of indication which is being given (*i.e.*, circuit breaker, tap changing switch

or meter ; in this case, circuit breaker). The second signal represents the particular unit affected and its new position. Each of these signals consists of a numbered train of impulses, the differentiation between signals being obtained by counting the number of impulses. The trains of D.C. impulses are produced in the sub-station supervisory cabinet and transmitted to the voice frequency equipment where they are converted into impulses of alternating current at voice frequency. These V.F. impulses are transmitted over the Post Office line to central control where they are received in the associated voice frequency signalling equipment, on a thermionic valve amplifier-rectifier. The output from this amplifier-rectifier consists of impulses of direct current which are transmitted to the associated supervisory cabinet, and there actuate selectors according to the number of impulses received.

When both trains of impulses have been received the new indication is completely determined and might now be given on the board. Since, however, line interruptions or abnormal conditions may possibly arise, when impulses may be distorted or lost during transmission, the signals received and stored may not correctly interpret the condition to be indicated. Indication is therefore withheld momentarily and two signals consisting of numbered trains of impulses are sent back from the central control station to the sub-station to confirm the interpretation. If the latter is correct, the two signals received back at the sub-station should agree absolutely with the signals transmitted. If this condition obtains, a further signal is sent to the central indicating station which causes the selected indication to be given, that is, the red lamp associated with the affected circuit breaker on the top section of the main indicating board will be extinguished and the green lamp will light. To call the control officer's attention to the fact that a changed indication has been given, an audible alarm is sounded, and to enable him to locate quickly which indication has changed the white lamp associated with the changed breaker is caused to flash slowly. The audible alarm may be silenced by momentarily operating an alarm reset key on the desk, but the white lamp continues to flash until the control officer alters the position of the corresponding manually operated rotary indicator on the miniature diagram desk. This ensures that the diagram is always kept up to date.

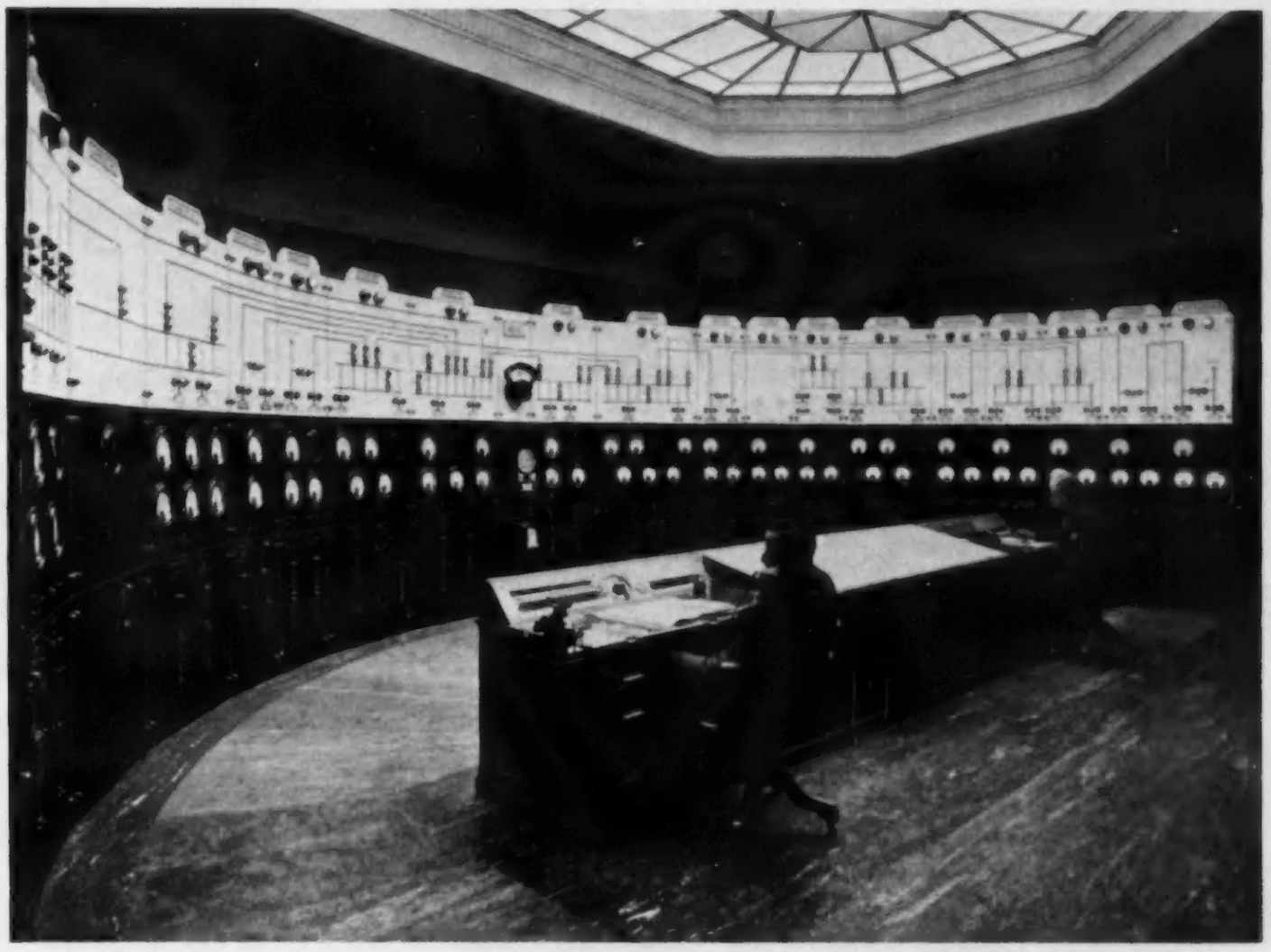


Fig. 11.—General view of Central Control Room, Birmingham.

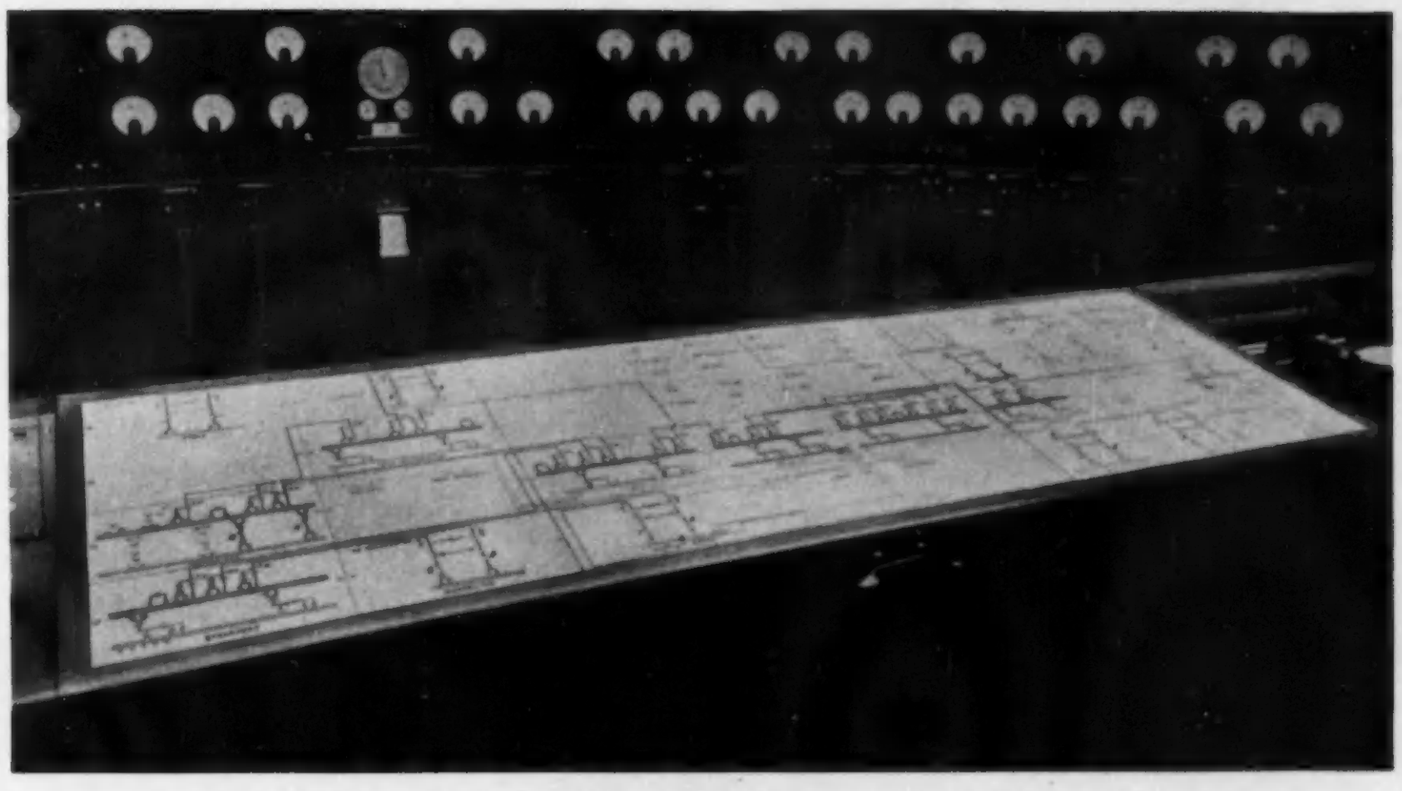


Fig. 12.—Miniature diagram desk at Central Control.

Should any line or other condition arise to mutilate the impulses forming the original signals initiated at the generating station, resulting in disagreement between these signals and those sent

back from central control for "check back" purposes, repetition automatically takes place until accurate receipt of the signals is confirmed and the indication is then displayed in the control room.

TAP CHANGING SWITCH SIGNALS.

In the supervisory cabinet at the sub-station is one 15-position selector which is associated with each tap changing switch, and is maintained in a position corresponding to the indication being given of that tap changing switch on the main indicating board. When the tap changing switch position is altered by the local control engineer, a disagreement will exist between the position of the contact arm mounted on the tap changing switch and the position of the selector mentioned above. This causes signals to be sent to the central control exactly as described in the case of circuit breaker indications, except that the first signal will represent that the change has occurred on No. 1 transformer or No. 2 transformer as the case may be, and the second signal the new position of the tap changing switch. The signals are checked back in the manner already described, and if correctly received the new indication is given on the main indicating panel. An audible alarm is sounded, and a red lamp associated with

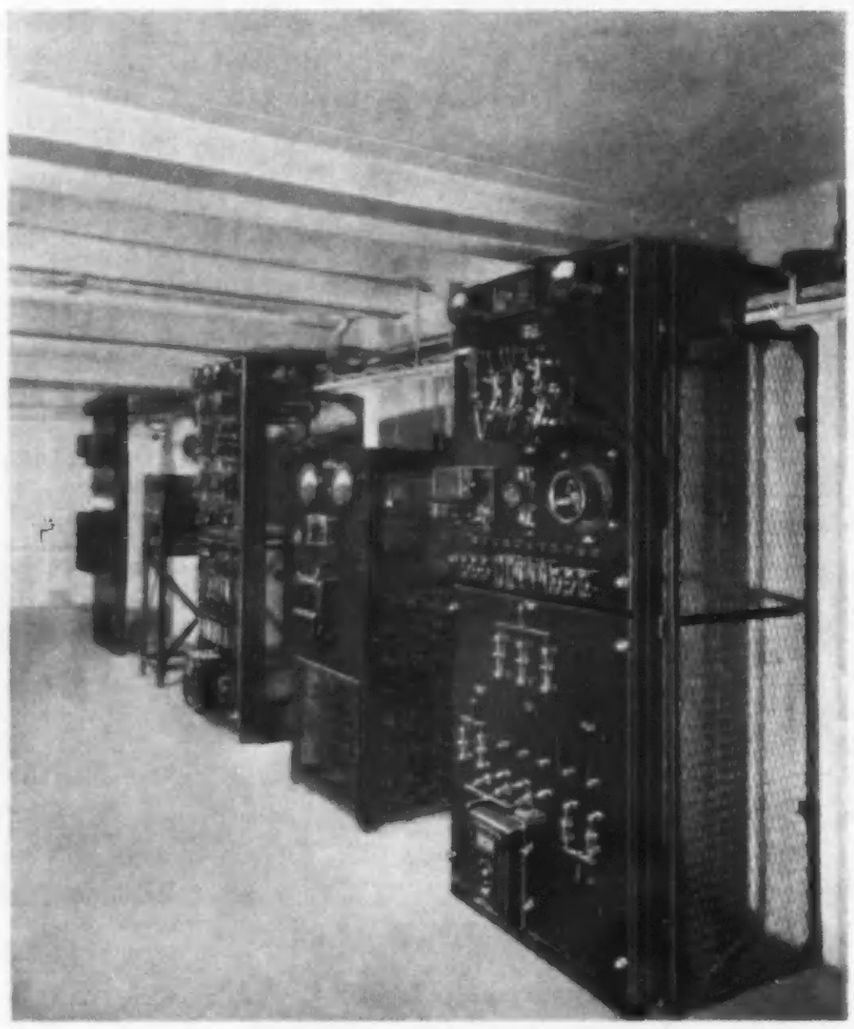


Fig. 13.—Battery charging control panels at Central Control.

the changed transformer glows to attract the control officer's attention. To indicate the number of steps which the tap changing switch has taken and the direction of change, the lamp indicating the old position is caused to flash. These conditions are reset to normal by the operation of a common "alarm reset" key, leaving only the new indication lamp glowing. When changes are effected in the positions of the tapping switches on both transformers the two indications are sent through in succession.

METERING.

The initiating meters at the generating stations are standard Midworth repeating wattmeters, arranged to meter a three phase supply with unbalanced load and in the majority of cases to summate the loads on two feeders. These transmitters control the direct current over the two outgoing pilots so that the value of this current is directly proportional to the reading of the initiating instrument. The pilots terminate on a Midworth power-driven receiver in the auxiliary plant house. This instrument consists essentially of a moving coil meter equipped with a motor-driven auxiliary or slave pointer which is constrained to take up a position in agreement with the main pointer. The slave pointer, being motor-driven, has a considerable torque and consequently can be arranged to rub over a series of studs with one of which it will always make reliable contact. As there are 50 studs within the full scale deflection, the stud on which the slave pointer is resting will indicate with an accuracy of + or − 1 per cent the reading of the main pointer which in turn is a measure of the deflection of the initiating meter in the generating station. It will be appreciated that the problem of transmitting an indication of the position of this slave pointer on its set of contacts to the central control is similar to that of transmitting the indication of the contact on which the tap changing switch is resting. A 50-point selector is provided in the supervisory cabinet and is maintained in agreement with the meter indication being given on the main indicating board for this particular meter. The 50 points of this selector are wired out to the 50 points of the associated power-driven receiver and so long as the two are in agreement a relay is held operated. Should the meter indication change by more than a maximum of 2 per cent the power-driven receiver will move on to another stud and the relay will release. This initiates signalling to central control in the usual manner, the first signal indicating the particular meter affected and the second signal positioning a selector at central control in accordance with the position of the power-driven receiver. This selector drives the arm of a 50-point potentiometer across which is a constant D.C. potential; the output from this potentiometer is therefore proportional to the position of the selector. The potentiometer is connected to a moving coil voltmeter on the main indicating board, the deflection of which is therefore proportional to the reading of the indicating meter in the distant generating station. The position of

the selector at the sub-station is now brought into agreement with the new position of the power-driven receiver and the equipment is now ready to transmit the next change.

As it is not necessary to keep the meters up to date continuously, and as a constantly varying meter will result in excessive use of the signalling

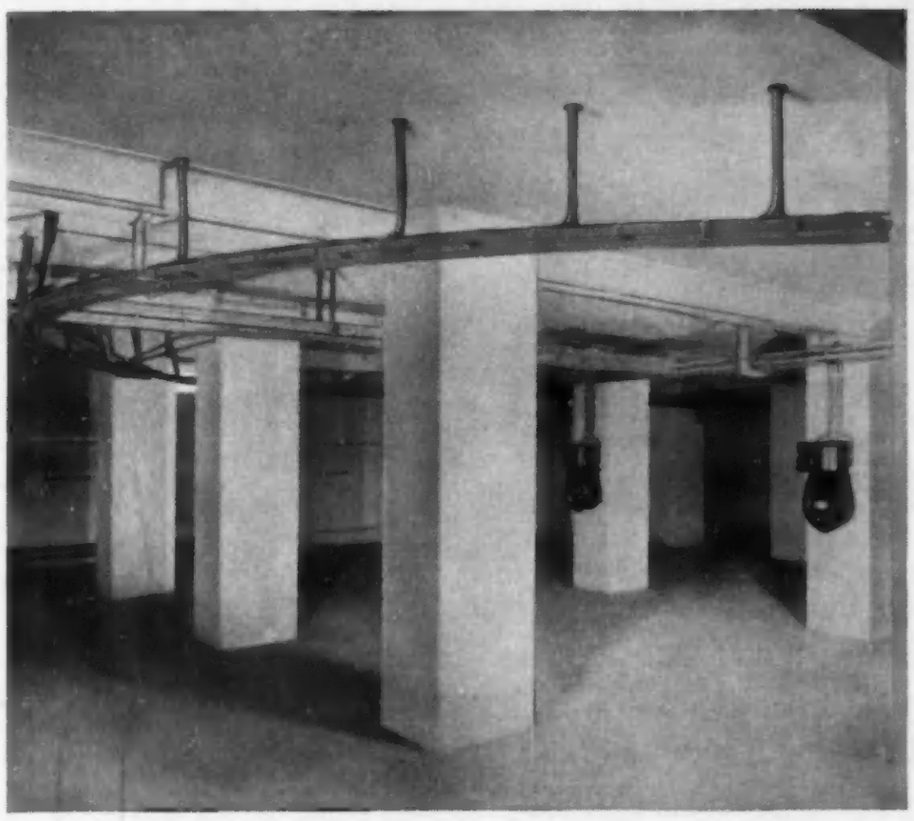


Fig. 14.—Cabling under Central Control Room.

equipment, a key is provided on the main control panel, which, while in the normal position, prevents meter readings from being transmitted. When operated in one direction the megawatt indications are transmitted, and when operated in the other direction megavar indications are transmitted.

TELEPHONE COMMUNICATION.

The number of different types of calls which may be set up is so large that only a few of the more common cases will be considered.

(*a*) *From generating station to central control.*

On the face of the cordless telephone exchange board in the generating station (fig. 3) is a key marked C.I.S. (Central Indicating Station); to make a telephone call to control, this key is operated in a downward direction and the telephone instrument lifted from its hook. This causes signals consisting of the usual two trains of impulses to be sent to central control, followed by the usual check back signalling. If the selection is found to be correct a further signal is sent to cause a lamp associated with the calling station on the turret of the control officer's desk to light, and an audible alarm to sound.

To answer the call, the control officer operates the key below the call lamp in a downward direction. This connects his telephone instrument to the calling line, and also lights the associated engaged lamp on the other position and operates the "engaged" indicator associated with this line on the manual board in the offices. Conversation can now be carried on. To clear down on the completion of the call the keys at both stations are restored to normal and the telephone instruments restored. If it is desired to transfer the call to one of the administrative offices, the control officer operates the key on the turret momentarily in the upward direction and then restores it to normal. This causes the associated call signal to operate on the manual board and an audible warning to be given.

(*b*) *From central control to generating station.*

To make a call to a generating station the control officer operates the associated key on his desk turret in the downward direction. This causes the usual two signals to be transmitted to the required sub-station, and checked back. If correct, a relay is operated which starts up a ringing machine at the sub-station which sends a ringing signal over the telephone wires from the sub-station to the generating station. This causes the signal above the "C.I.S." key on the generating station cordless board (fig. 3) to operate and gives an audible warning. The call is answered by operating the "C.I.S." key in the upward direction and lifting the telephone instrument.

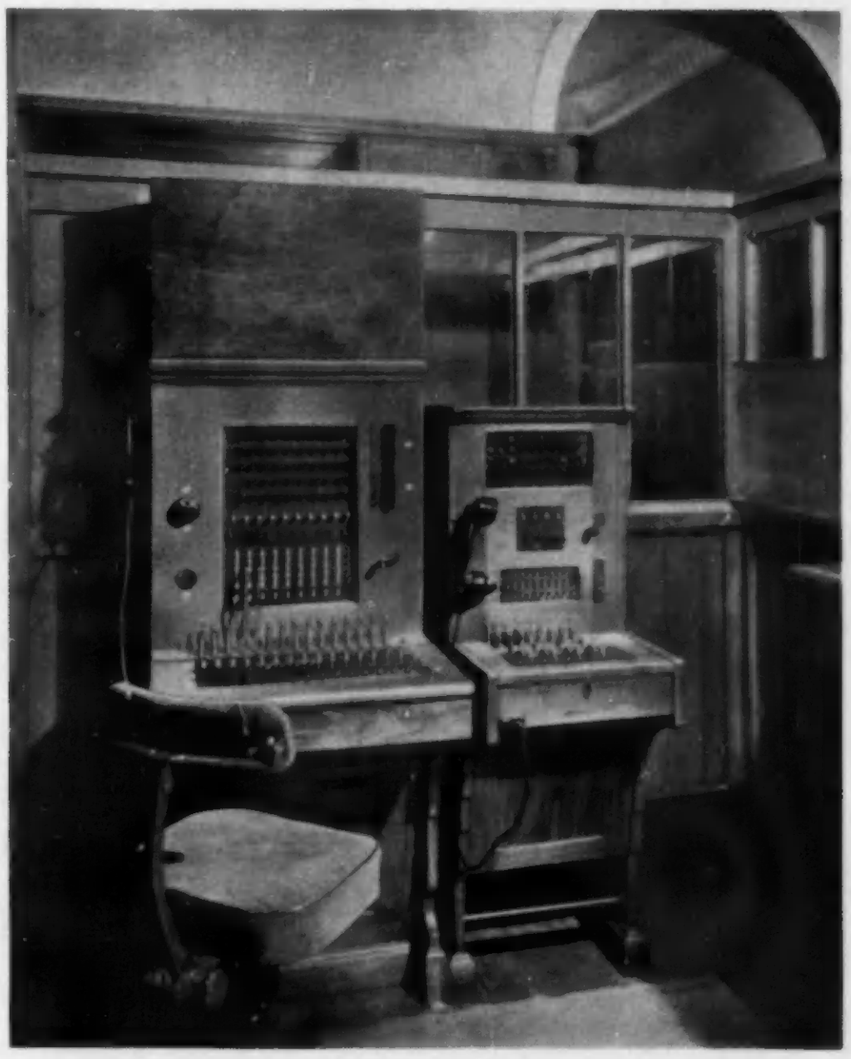


Fig. 15.—Telephone switchroom, District Office, Birmingham.

During certain periods when testing is in progress and the C.E.B. technical staff is in attendance in the A.P.H. (Auxiliary Plant House) it is desired that all calls originated by central control shall be handled at that point. A key is therefore provided on the A.P.H. telephone instrument which cuts off the line to the generating

station from the supervisory equipment and terminates it on a separate bell. With this key operated, calls incoming from central control sound an audible alarm in the A.P.H. but not in the generating station. The A.P.H. attendant answers the call, and if the generating station is required, restores the generating station cut off key and transfers the call.

EMERGENCY TELEPHONE OPERATION.

It has been mentioned previously that the essential feature of the whole communication system is the telephone service. If all other facilities fail it is possible to run the system by means of the telephone alone. It is consequently imperative that no failure of the supervisory or metering equipments should put the telephone service out of action. From the preceding description of the method of setting up telephone calls it will be seen that a failure of the supervisory equipment or the voice frequency signalling equipment might prevent telephone calls being made. Consequently an emergency telephone system is provided which is independent of the supervisory and V.F. signalling equipment.

For each sub-station an emergency service key is provided in the central control station. When this key is operated the whole of the supervisory and V.F. equipment is cut off, and the line is connected directly to the telephone on the desk. To call the generating station, the ordinary key on the turret is operated and a hand generator mounted in the knee-hole of the desk is turned. This sends ringing current out to the generating station where it operates a relay which in turn cuts out all the supervisory and V.F. equipment and connects the line directly to the telephone instrument. The ringing current then operates the calling signal, and the call is completed in the usual way. An emergency service key is also provided on the generating station cordless board and in the A.P.H., thus allowing emergency conditions to be set up from either station. The call is cleared down in the usual manner by restoring the call keys. Generally the operations involved in making telephone calls under emergency working conditions are the same as under normal conditions except that the hand generator is used for calling.

PRIORITY OF SIGNALS.

Owing to the number of types of signals sent over the same pair of wires it is necessary to arrange some order of priority. This is arranged to be variable, but in this equipment the present conditions are :—

(1) Circuit breaker signals have preference over all others.

(2) The telephone condition has preference over metering signals.

(3) Metering signals have no preference.

Twickenham Bridge Illuminated at Night.

The new Twickenham Bridge on the Chertsey arterial road illuminated by Osram lamps in standards mounted on the parapet.

The Bright Annealing of Metals.

By VERDON O. CUTTS.
Industrial Heating Dept. of The General Electric Co., Ltd.

THE demand for plant and processes for bright annealing is greater now than it has ever been. This applies equally to ferrous and non-ferrous metals and alloys; also to the annealing of parts between different operations during manufacture and to the annealing of finished products. The increased demand has grown very rapidly; in fact its suddenness and insistence have been the outstanding features of metallurgical interest during the last few years. The chief reason for this sudden demand is to be found in the attitude of the manufacturer towards the question of the bright annealing of metals, an attitude which has changed from one of doubt to one of enthusiasm. It is therefore proposed in this article briefly to describe the latest developments, processes and equipment now available for the bright annealing of metals.

MAIN CONSIDERATIONS.

Bright annealing processes may be divided into two main categories; the batch type and the continuous type. In the former, unit charges of a pre-determined and approximately uniform size are treated, giving an intermittent output at regular intervals ranging from a few hundred pounds to a few tons of annealed material. With the second, or continuous type, there is a constant output of individual pieces, or of strip, or wire, throughout the working period. Obviously the latter process is the more convenient where it is desired to install the annealing plant in the line of production. Convenience, however, is not the only consideration involved. Metallurgical considerations frequently determine which type of plant should be adopted. For instance, in some cases the comparatively long annealing cycle of the batch type, which is ideal for some metals, would produce undesirable grain growth in others, with the result that the annealed metal would not possess the desired physical properties. Although there are problems which are common to both types, there are others which are peculiar to each. It is therefore necessary to consider them separately. It is proposed to deal mainly with the batch type, first as applied to iron and steel, and secondly as applied to copper and other non-ferrous metals and alloys.

ATMOSPHERE CONTROL.

Obviously the first essential for bright annealing is atmosphere control. The surface of the charge must be protected from atmospheric oxygen, carbon dioxide, water vapour and other oxidising agents. Further, it is necessary that the non-oxidising atmosphere should neither carburise nor decarburise the surface of the charge.

The methods adopted in the past to obtain these conditions have certain inherent features which have seriously limited their adoption. They consisted in either packing the charge in heavy cast or wrought iron boxes filled with borings, or providing an artificial gas atmosphere within a sealed pot or box containing the charge. Both these methods involve

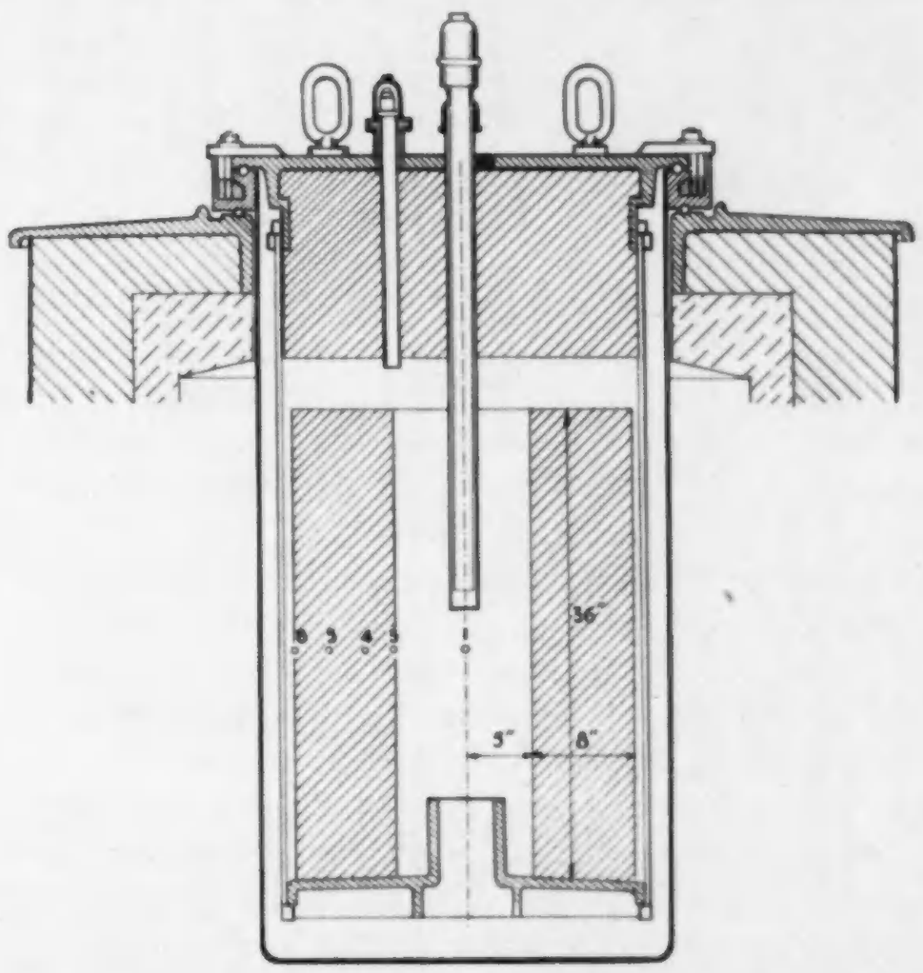
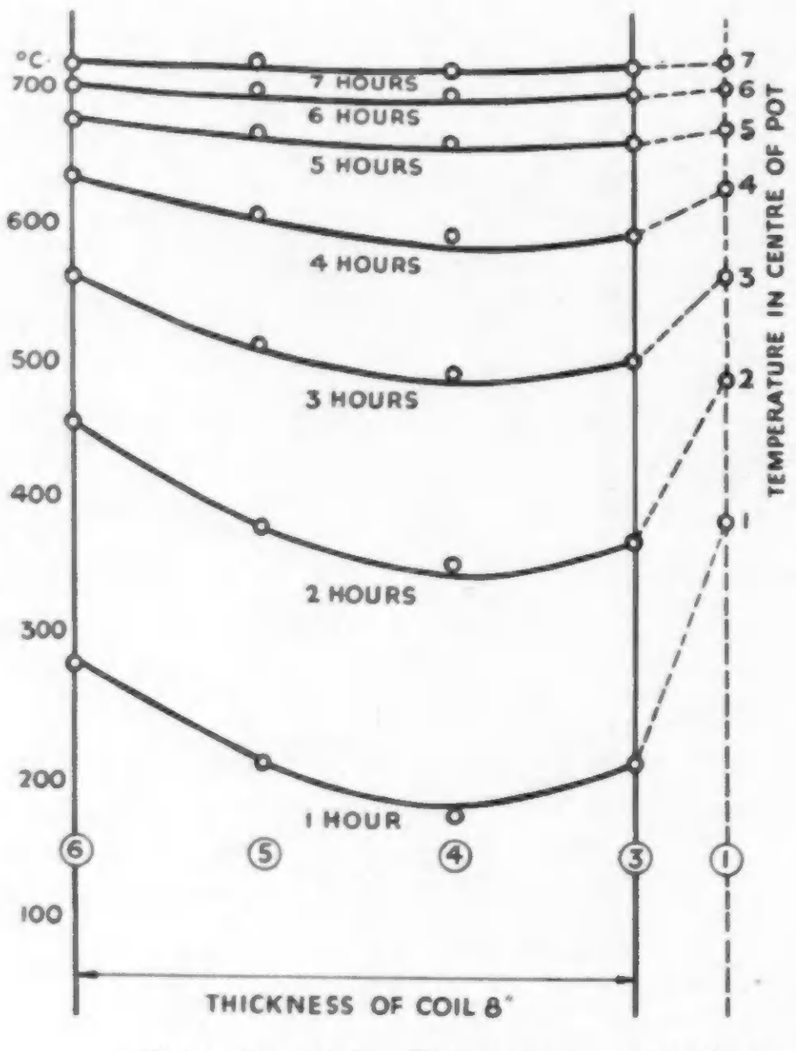
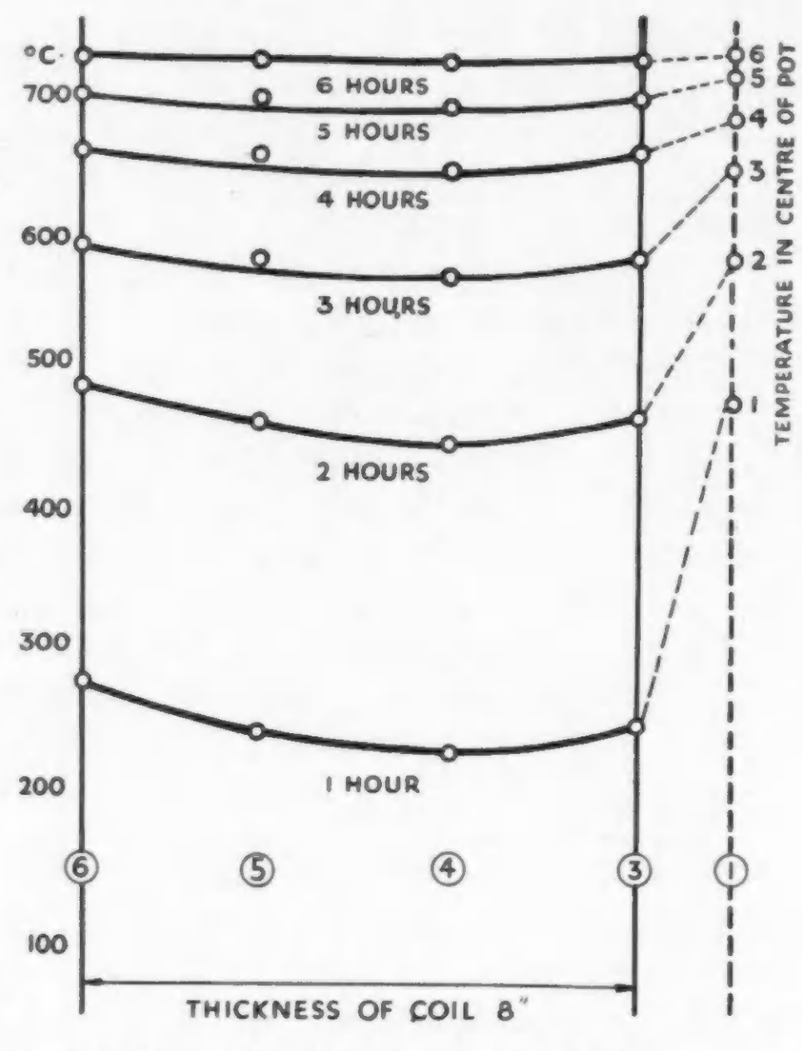


Fig. 1.—Diagrammatic section of a Grunewald pot, showing the position of the thermocouples inserted in the charge for testing purposes.

the heating of heavy containers (with or without borings), with a consequent serious increase in the cost of heating per unit of useful product treated. The corollary of this is an excessively long heating and cooling cycle, which increases the tonnage of metal locked up in the course of manufacture, holds up deliveries and makes unnecessarily heavy demands on workshop space, lifting facilities, etc. These methods involve higher labour charges than obtain with ordinary open annealing of similar material, and also make a greater demand on the skill and attention of those in charge of the plant. The nett result of these several unfavourable features was to make bright annealing considerably more expensive than ordinary annealing, and generally to retard its

adoption. A tremendous amount of valuable work has been done recently in connection with the economic production of artificial gas atmospheres suitable for bright annealing. Ammonia crackers and burners have been developed, which are largely





Figs. 2 and 3.—Temperature readings taken hourly by thermocouples shown in Fig. 1.

capable of being automatically controlled, and of adjustment to produce pre-determined nitrogen-hydrogen mixtures. Ingenious methods have been devised for pre-mixing two or more gases in such proportions as to produce desirable mixtures for annealing purposes, and useful work has been done in the pre-treatment of ordinary town gas, by decomposing it pyrogenically so as to produce an artificial atmosphere suitable for the bright annealing of steels of various carbon contents. All these developments have, and must continue to have, a very important influence on the future of bright annealing processes. Their greatest potential field of application would appear to be in connection with *continuous* bright annealing processes, because it has now been proved that the provision of such artificial gas atmospheres is not essential for the bright annealing by the batch process of iron and steel and several other metals and alloys, which are commonly used in industry. This being established, the use of an artificial gas atmosphere is unwarranted on the scores of economy, convenience and simplicity of operation.

Fig. 4.—A Grunewald installation in the works of J. F. Ratcliff (Metals), Ltd., Birmingham.

GRUNEWALD PROCESS.

The Grunewald process (which was fully described in the *G.E.C. Journal*, Vol. III., No. 2), ensures a uniformly annealed product which is really bright, at a cost which is comparable with that of ordinary annealing. It is entirely independent of any artificial supply of gas, and differs from all other batch type bright annealing processes in respect of three essential details. The charge is supported on a cast base by nickel chromium suspension rods attached to the thermally insulated pot cover, from which the pot itself is also suspended. Consequently the envelope of the pot may be made of very thin

sheet material, and the weight of extraneous metal to be heated is reduced to a minimum. The design includes a simple but effective water cooled rubber seal, which is remote from the heated zone of the furnace, and consequently gives no trouble.

A non-return valve is provided in the pot cover, through which most of the air content of the pot is expelled during the heating process, due to expansion and vapourisation of any oil or grease adhering to the charge. During the subsequent cooling period a partial vacuum is built up within the pot, and, owing to the absence of atmospheric oxygen or other oxidising agent, a perfectly bright product is ensured. It will also be obvious that the conditions prevailing inside the pot preclude any possibility of either carburisation or decarburisation of the surface of the charge.

The rate of heating of a charge of steel strip in coils and the uniformity of the temperature throughout the charge is illustrated in figs. 1, 2 and 3. Fig. 1 shows diagrammatically a charge of strip inside a Grunewald pot. Thermo-couples were inserted in the numbered positions shown. The temperature readings taken after each hour of the heating period are shown in fig. 2. After seven hours there was no appreciable variation of temperature in the charge. The result of a similar test is shown in fig. 3; in this instance the time required to obtain a uniform

Fig. 5.—Another view of the installation shown in fig. 4, showing the treatment of brass strip.

temperature throughout the charge was reduced to six hours. The improved result shown was obtained by inserting segments cut from scrap copper sheet between the individual coils, thus providing a series of paths of high heat conductivity into the body of the charge. This feature, which is patented, has a very real economic value, reducing the overall current consumption by saving the radiation losses for one hour per charge and increasing the output of the

Fig. 6.—View showing the heating elements of a Grunewald bright annealing furnace.

furnace by approximately 14 per cent. It is evident that a charge heated so uniformly as is shown in these diagrams, must be as nearly perfect for subsequent fabrication purposes as it is possible to attain in practice. Cold rolled steel strip is being annealed in this manner, with a perfectly bright finish, with a power consumption of 170 to 180 kWh per ton where recuperation is obtained by the use of a thermally insulated trench.

This same process is used with equally excellent results for the annealing of iron and steel wire, copper strip and wire in coils, fine copper wire on spools, nickel and nickel alloys in various forms and for other similar purposes. There are 76 Grunewald installations in regular commercial operation, and the quality of the anneal is so nearly perfect, that in a few instances this process is used even where a bright finish is not required, but where a thoroughly reliable and uniform anneal is necessary.

The only labour required is that which is necessary for charging, transferring and emptying the pots.

The Grunewald process is not suitable for the bright annealing of brass or nickel-silver, or any other alloy which contains volatile constituents, or for which a short annealing cycle is necessary to produce the desired physical properties. In some cases, however, it is advantageous to use the simple sealing device and the light pot of the Grunewald process in conjunction with a suitable controlled artificial gas atmosphere.

BELL FURNACE.

The bell type of furnace is also used for bright annealing. This resembles an inverted pot type

furnace, which in the majority of cases rises and falls over covers under which the charge is placed. With this type of furnace it is necessary to have an artificial gas atmosphere. Further disadvantages of

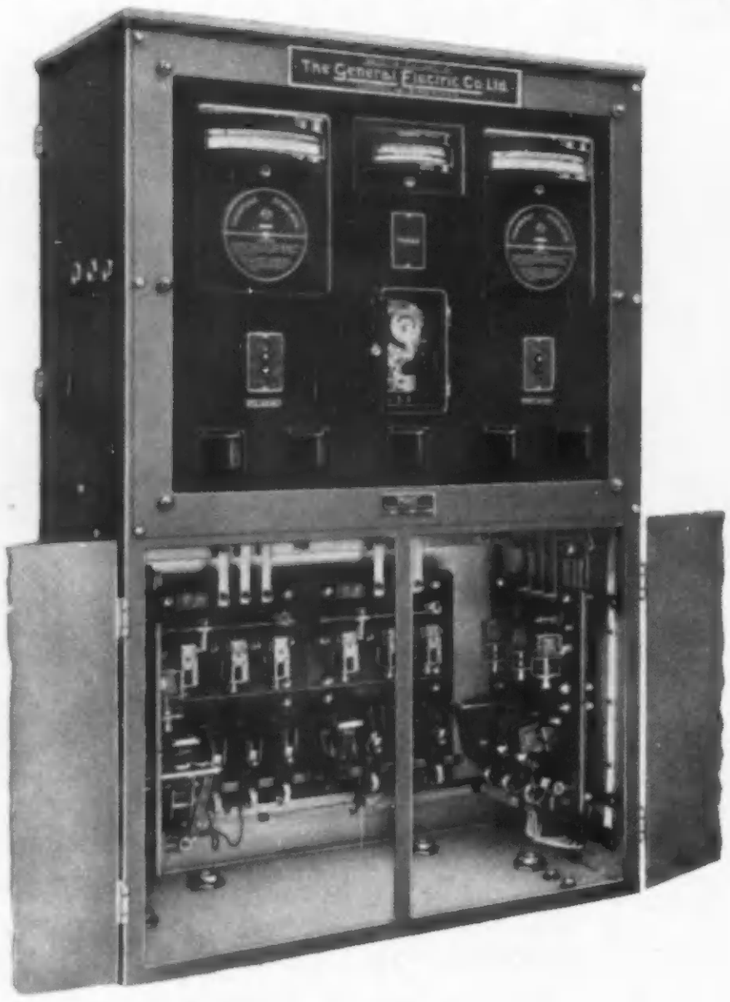


Fig. 7.—Typical G.E.C. control panel for Grunewald installations.

this type are, firstly, the frequent movement of the furnace (which tends to weaken the structure), and secondly, the considerable volume of heat (stored up

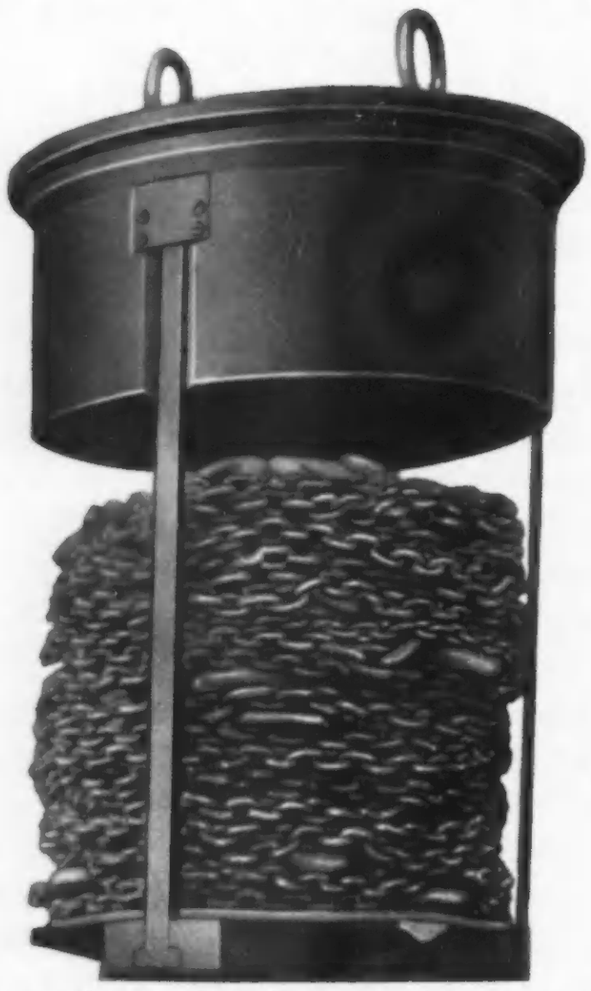


Fig. 8.—According to B.O.T. regulations, chains used at wharfsides must periodically be annealed. View shows a charge of chain ready for treatment.

in the base, which is moved with the charge to the cooling station), which is lost, and also tends to retard the cooling of the charge. There are also stationary bell type furnaces, the hearths of which are portable within prescribed limits. Here, again, if bright annealing is the objective, an artificial gas atmosphere is essential, facilities for cooling under cover must be provided, and an adequate sealing device which will retain its effectiveness in spite of being frequently broken, is required.

There are several other batch type bright annealing furnaces, most of which have a very specialised and therefore limited application. Shuttle and ram type furnaces are used for bright annealing silver in an atmosphere of steam, and pit type furnaces are used for annealing transformer sheets in hydrogen.

Before leaving the subject of batch type bright annealing furnaces, mention should perhaps be made of the fact that some bright annealing processes do not prevent oxidation of the charge, but rather rely on reduction of the oxide formed, during the later stage of the process. By such means it is certainly possible to obtain a bright product, but, where it is possible to prevent the formation of scale, prevention is obviously better than cure. The elimination of oxidation and scaling gives an increased economy in material, and the charge is brought out precisely to specification so far as gauge or dimensions generally are concerned.

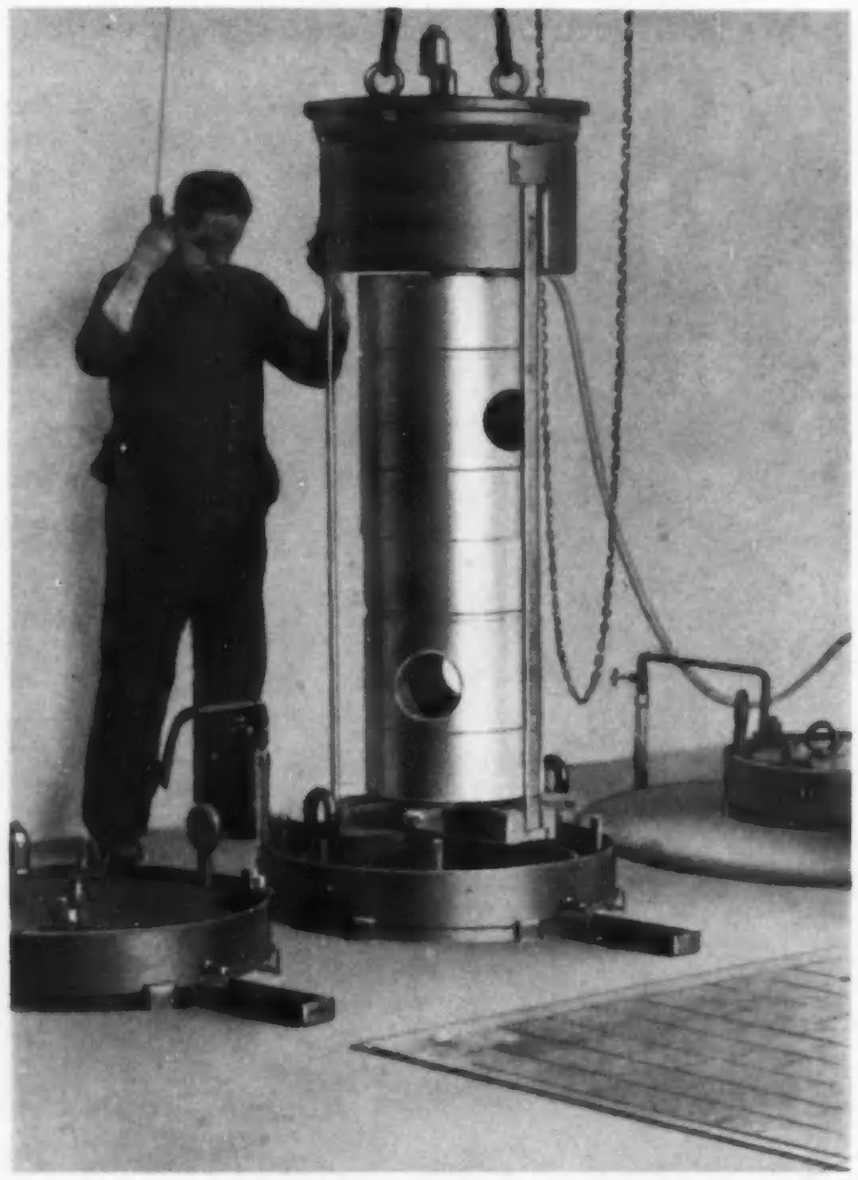


Fig. 9.—Lowering a charge of Diesel-engine pistons into the pot of a Grunewald furnace.

CONTINUOUS BRIGHT ANNEALING.

Continuous bright annealing plant is more varied in design than that of the batch type. Nearly every

installation must be designed specially to meet the individual requirements of a particular plant. A brief review of some of the problems encountered will probably be of interest, and will also serve the purpose of giving a clearer insight into the possibilities and practical considerations involved.

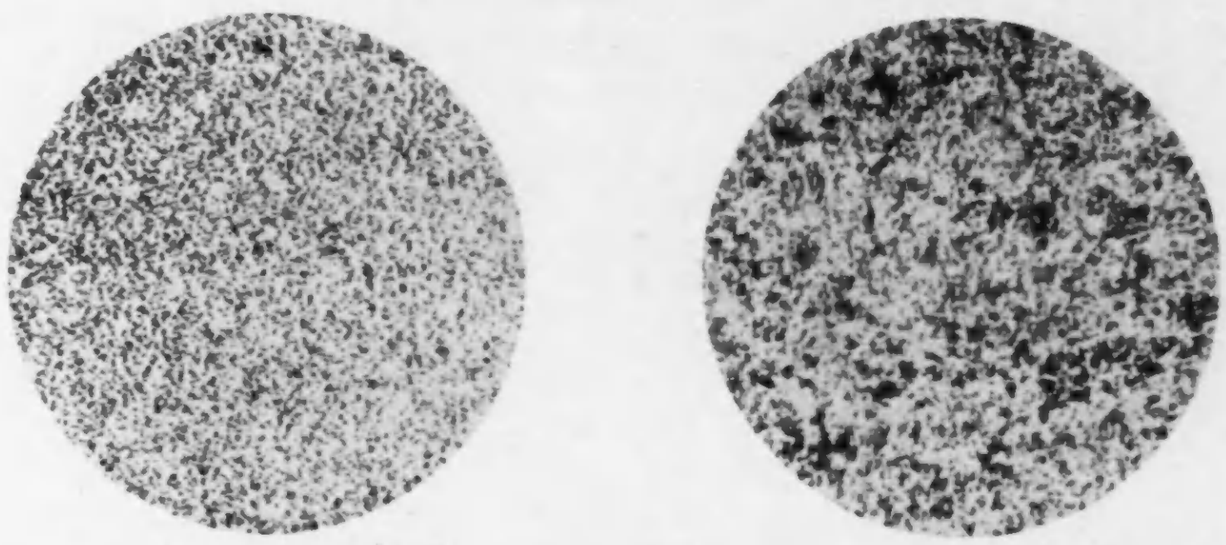


Fig. 10.—Two photomicrographs of silver steel wire ; on the left annealed at 680°C and (right) annealed at 680°C and normalised at 850°C. Magnification 35 in both cases.

The disposition of the heating elements within a continuous furnace is usually such as to give a series of zones which are not only capable of working at different temperatures but are also separately controlled. The length of these zones and their electrical loading must be governed primarily by the heat absorption of the charge. All continuous type furnaces must be provided with an artificial gas atmosphere for bright annealing purposes. The method adopted for conveying the charge through the furnace must obviously depend upon the nature of the charge. Strip and wire are frequently drawn through long rectangular furnaces by means of winding gear situated at the exit end of the furnace. In the case of strip it is necessary to employ a tensioning device to control the amount of sag inside the furnace. For the annealing of large numbers of individual pieces it is customary to use either an endless belt conveyor hearth or an intermittent mechanically operated pusher arrangement working in conjunction with trays or containers. Alternative methods for conveying the charge are found in the walking-beam type of furnace, the multiple car hearth type, and, for small work, the revolving drum with a helical conveyor. It will be appreciated that with such varied methods of conveying the charge through a furnace which must have an artificial gas atmosphere, the provision of a suitable seal to preserve this atmosphere is very important. Where the charge must be quenched after heating, the sealing problem is comparatively simple. Also, where the charge is in the form of strip or wire fed from coils, the sealing of the furnace is not very difficult, but when dealing with charges of irregular contour, which must be perfectly dry after annealing, this question of sealing the furnace becomes one of considerable difficulty. The other main consideration is that of cooling or quenching the charge. Unless efficient means are adopted, the cooling zone becomes excessively long, and consequently the space occupied by the installation is increased, and the cost of the means of conveying the charge may become prohibitive. Here again, if the charge is of such a character that it may be quenched, the plant and its operation are very much simplified. If the charge is in the form of strip continuously fed from coils, the problem is not difficult, but with charges of irregular size and shape, which cannot be cooled by contact, the design of the cooling zone of the installation becomes more difficult.

The final choice between the batch and continuous types of bright annealing installation must depend largely upon whether a long or short heating and cooling cycle is required to produce the desired physical properties in the material treated. The relative convenience of the two types depends to a considerable extent on the processes immediately preceding and following the annealing operations. So far as the costs of bright annealing are concerned, these are lower with batch type furnaces than with continuous ones. This is particularly true where the Grunewald process can be employed, on account of the reduced weight of containers, and the fact that no artificial gas atmosphere is required.

The Electrification of a Semi-continuous Bar and Strip Mill.

NEW EQUIPMENT AT COURTYBELLA WORKS, NEWPORT.

By H. G. WEAVER, M.I.E.E.,
Chief Engineer to the Whitehead Iron and Steel Co., Ltd.

The development of continuous rolling in this country owes much to the initiative of Mr. L. D. Whitehead, who in 1907 formed the Whitehead Iron & Steel Co., Ltd. The original plans of this company included the purchase of the Tredegar Iron & Steel Works, of which Mr. Whitehead had previously been Works Manager.

In 1914 a site of 30 acres was acquired at Newport, upon which in 1919 the Courtybella Works was erected and equipped.

From time to time various extensions have been made, the latest of which is described in this article which has been contributed by Mr. H. G. Weaver, M.I.E.E., the Chief Engineer to the Whitehead Iron & Steel Co., Ltd.

THE completion of the new continuous strip mill at the Courtybella Works, Newport (Mon.) of the Whitehead Iron & Steel Co., Ltd. marks the fulfilment of a programme initiated some years ago. The original rolling mill installation at Courtybella Works consisted of a combined 12 in. tube strip and hoop mill, known as No. 2 Mill. To this was added in 1924 a cold rolling mill plant, and in 1926 an auxiliary bar mill to operate in conjunction with No. 2 mill. Subsequently in 1931 the No. 3 semi-continuous bar and strip mill was laid down.*

The original purpose of the auxiliary mill was to afford an alternative outlet to the No. 2 mill when orders were slack, so that the furnace and roughing section of that mill might provide to the auxiliary mill material for the production of small rounds, squares and flats. The installation of a new furnace, roughing and intermediate mills and other necessary plant, now offers an independent source of supply to the auxiliary finishing mill, the complete equipment forming the third mill of the continuous type at the works. The new mill, although last completed, is referred to as No. 1 mill. It should be recorded that should trade slacken, the finishing rolls of the original auxiliary mill can still be supplied from No. 2 mill.

As now laid out, No. 1 mill is designed to deal with rounds and squares from $\frac{3}{16}$in. diameter up to 1in. diameter, and flats and strip from $\frac{3}{8}$in. to $2\frac{1}{2}$in. wide. Provision has been made in order to meet the requirements of Whitehead, Hill & Co., Ltd.—a subsidiary company—and the general trade, to duplicate in tandem No. 13 and 14 stands, and install reels to enable wire rods to be produced; or

*A complete description of the undertaking as it existed upon the completion of No. 3 mill was published in the Iron and Coal Trades Review (Sept. 18th, 1931).

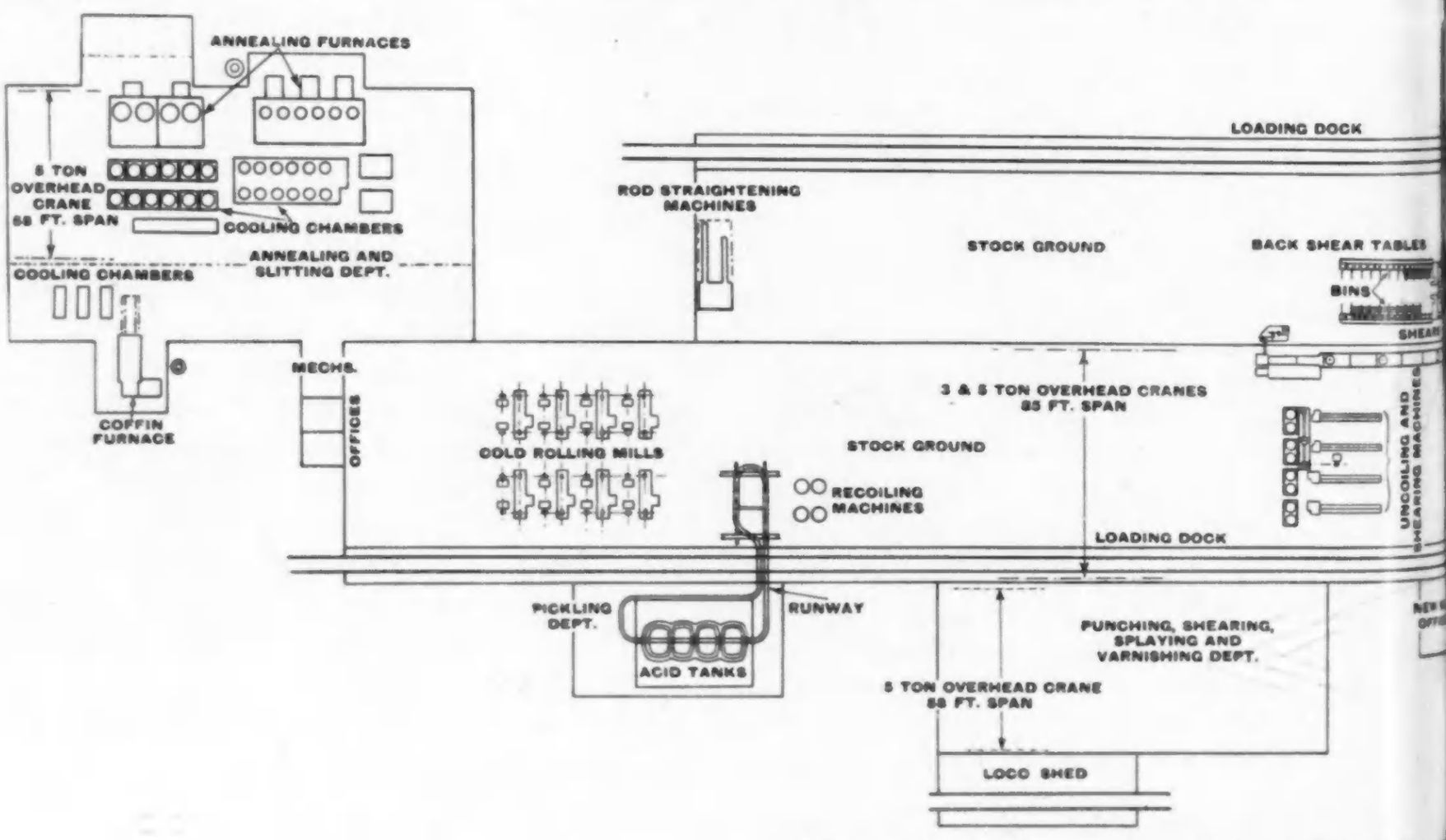


Fig. 1.—General arrangement plan of Nos. 1

alternatively to produce wire rods in a straight continuous mill by placing a group of 6 continuous rolls immediately in front of the intermediate mill.

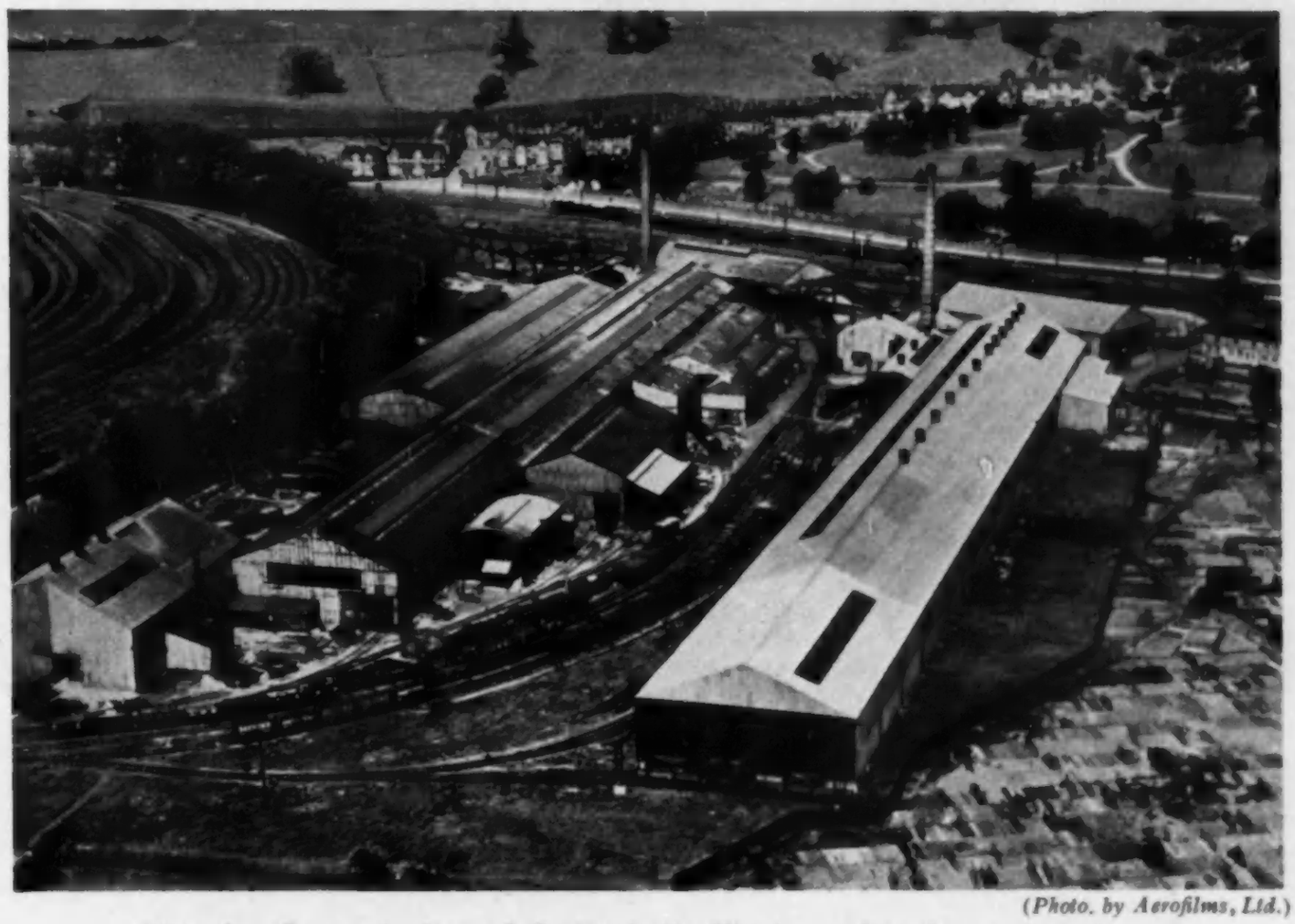
BUILDING EXTENSIONS.

The layout of Nos. 1 and 2 mills may be seen by reference to fig. 1, while the arrangement of individual sections of No. 1 mill is shown in fig. 3. It will be appreciated that considerable extension was necessary to the buildings, and the main building housing No. 1 mill, which is 71 feet wide, now extends to 840 feet in length. The common billet storage which connects the three mills has also been enlarged, and now has a total length of 875 feet. Additions made to the electric overhead crane equipment include a 7½ ton Vaughan crane in the main building, and a unit of 20-tons in the billet storage.

FURNACE.

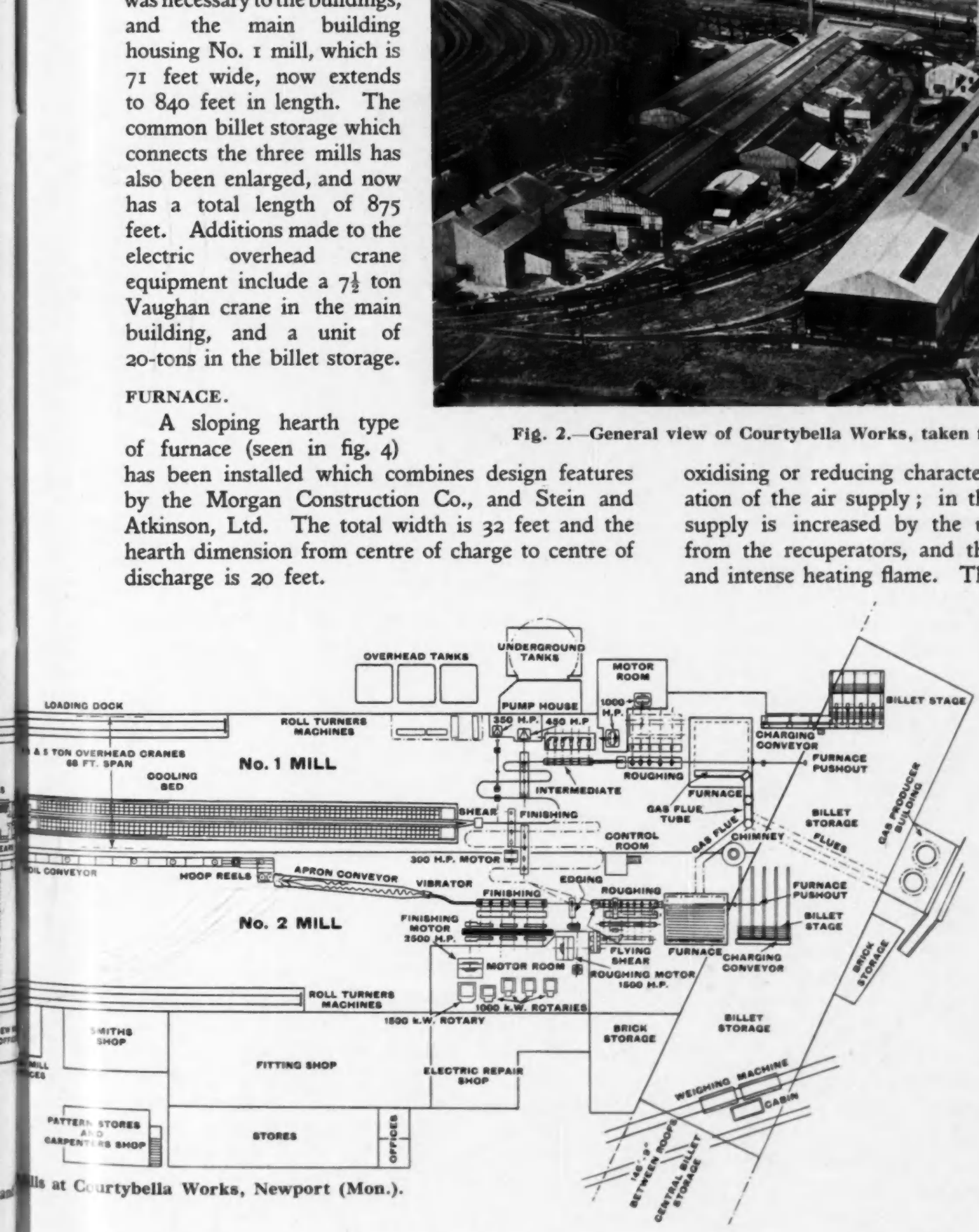
A sloping hearth type of furnace (seen in fig. 4) has been installed which combines design features by the Morgan Construction Co., and Stein and Atkinson, Ltd. The total width is 32 feet and the hearth dimension from centre of charge to centre of discharge is 20 feet.

A prominent feature of the furnace is the system of two zone heating, which is stated to give the maximum heating capacity per square foot of hearth, together with the minimum scale and fuel wastage. In this system the gas is introduced at two levels; at the lower one the gas has a non-oxidising or reducing character owing to the limitation of the air supply; in the upper zone the air supply is increased by the use of pre-heated air from the recuperators, and this gives an oxidising and intense heating flame. The effect is to produce



(Photo. by Aerofilms, Ltd.)

Fig. 2.—General view of Courtybella Works, taken from the air.



Mills at Courtybella Works, Newport (Mon.).

Fig. 3.—General view of No. 1 mill, showing the arrangement of the individual sections of the rolling mills.

the maximum heating temperature with an intervening blanket of non-oxidising gas.

The capacity of the furnace is so far in excess of that necessary for the light sections now being rolled that it has not so far been tested out to full capacity, but the indications are very promising. The system is remarkably easy and certain in control.

Between the furnace and the first stand in the roughing mill a steam dividing shears is installed which not only feeds the billet to the rolls, but at the same time, in the case of emergency, cuts it into the length required for the section being rolled, a duty which is normally performed by the rotary shears between the finishing rolls and the cooling bed, referred to later in this article.

THE ROLLING MILLS.

The roughing mill, fig. 4, consists of five stands of continuous rolls 14in. in diameter by 31½in. long. It is driven by a 1,000 h.p. direct current motor through a double helical reduction gear and a train of gears with machine cut straight teeth all enclosed in an oilbath. On emerging from the last stand of roughing rolls the bar is cropped by an "Edwards" flying shear in order to remove the cold end.

The intermediate roughing mill is placed directly in tandem with the roughing mill (as shown in fig. 3), with an intervening space of 24 feet. There are six stands of continuous rolls, the first four having rolls 12in. in diameter and 15½ins. long, and the last two rolls of 10 ins. diameter and 15½ins. long.

This mill also is driven by a 1,000 h.p. direct current motor through machine cut bevel gearing. The motor is direct coupled to the main bevel gear shaft which, together with the roll pinions are all enclosed in one gear case of welded steel construction to form a very compact drive. All the shaft bearings, gears, and pinions are lubricated with oil under pressure from a common system. Pressure gauges which operate electric alarms when the oil pressure falls below a safe value are fitted on the system.

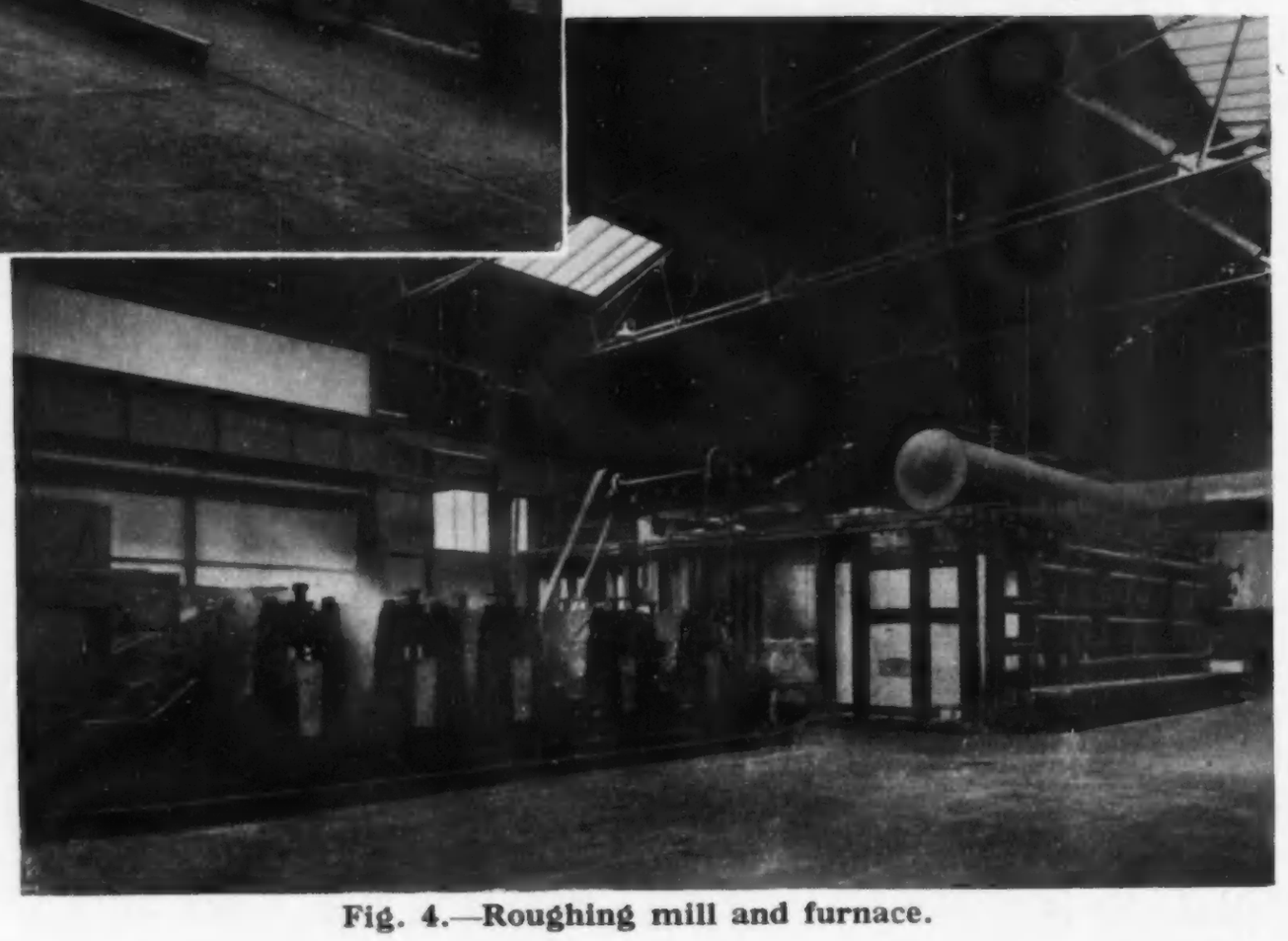


Fig. 4.—Roughing mill and furnace.

The finishing mill, fig. 5, comprises four looping trains, two of which (Nos. 11 and 12) have rolls 10ins. in diameter by 24ins. long, and two (Nos. 13 and 14) have rolls of 9½ins. diameter by 13ins. long. Nos. 11 and 12 are driven by a 450 h.p. motor, No. 13 by a 350 h.p. motor, while the full load rating of the motor driving No. 14 is 300 h.p. All the stands are direct coupled to the respective motors.

Repeaters are used between the intermediate roughing mill and No. 11 stand, also between stands Nos. 12 and 13.

CUTTING AND COOLING.

After leaving the finishing rolls the bar enters a mechanically operated switch trough, which serves two purposes. First it diverts the finished bars alternately from one side to the other of the double cooling bed, and secondly it provides for the automatic cutting, through a rotary shear of special construction, of the incoming bar to suit the length of the cooling bed, which is 230 feet. This enables

the billet to be rolled in one length, producing a finished bar up to 2,500 feet long, which the rotary shears automatically cuts into lengths suitable for the cooling bed. This method not only increases the output but materially lessens the manual labour, and the wear on the guides.

The cooling bed (fig. 6) is of the Edwards double sided oscillating saw toothed type, in its most modern form, the bars being carried down the centre of the bed upon two lines of positively driven rollers. After reaching the proper position they are oscillated across either to right or left. After passing over the cooling bed the bars are assembled on the dead plates, from which they are mechanically pushed laterally on to the live rollers to convey them to the two shears, one of which is placed on each side of the cooling bed. These shears have 20in. blades, are furnished with heavy fly wheels, and are motor driven.

After being cut, the bars are conveyed by live rollers to the bunkers for loading, or subsequent handling. Beyond this point is accommodation for

Fig. 5.—Finishing mill, looking in the direction of the cooling bed.

long bars, from which urgent stock orders are cut.

The loading bay provides for 22 wagons.

ELECTRICAL EQUIPMENT.

The mill is electrically operated throughout, the new electrical equipment having been designed and manufactured by The General Electric Co., Ltd. Reference has already been made to the capacity of the motors, but certain further details are of interest. Illustrations of the machines are given at figs. 7, 8 and 9. Speed ranges are given below :—

(1) Roughing mill } Each 1,000 h.p. 165/500
(2) Intermediate mill } r.p.m.
(3) Finishing mill, stands Nos. 11 and 12. 450 h.p. 185/555 r.p.m.
(4) Finishing mill, stand No. 13. 350 h.p. 300/900 r.p.m.
(5) Finishing mill, stand No. 14. 300 h.p. 250/625 r.p.m.

These motors are of the open type and operate on a 500 volt D.C. circuit. They are shunt wound machines fitted with light stabilising windings, also compensating and interpole winding. Full H.P. output is given at any speed over the ranges, with an inherent speed regulation between no-load and full load not exceeding 3 per cent. Speed control is effected by means of a rheostat in the shunt field.

The design of the motors ensures great mechanical strength in order that they may be capable of withstanding the heavy duties inherent in rolling mill operation. The driving bearings are fitted with special thrust collars to take the end thrust which might occur should the intermediate torque shaft fail.

MOTOR CONTROL EQUIPMENT.

For the control of the four rolling mill motors a nine panel flat back switchboard, fig. 10, is installed, one panel controlling the 500 volt incoming 5-wire direct current supply, one supplying two 200 amp. distributing circuits, while the remaining seven panels control the mill motors.

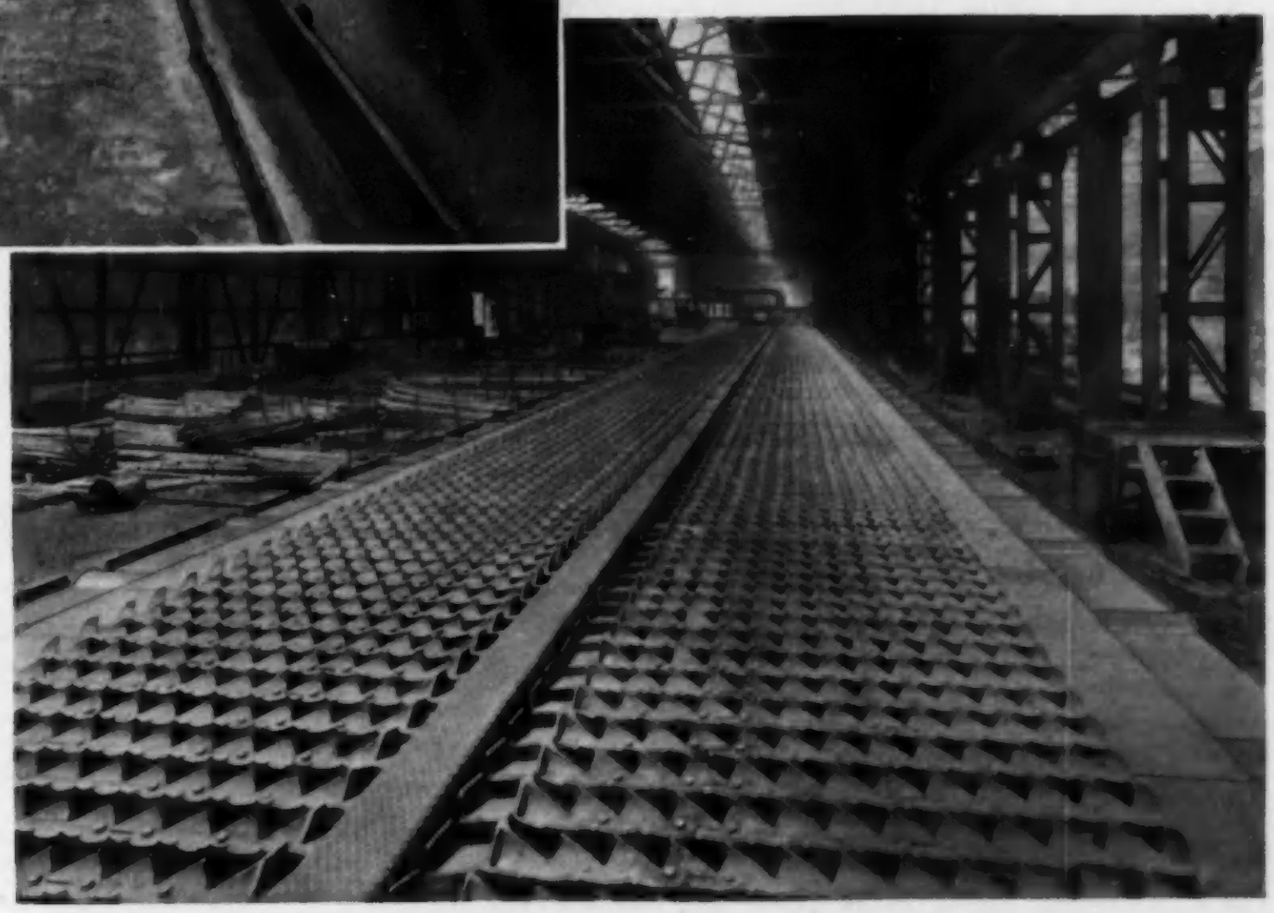


Fig. 6.—Cooling bed, 230 feet long. View looking towards mill.

The switchboard is built in the form of an "L" and is installed along two walls in one corner of the building. Expanded metal doors prevent unauthorised entrance to the back of the switchboard.

In all cases the circuit breakers are equipped with overload and under voltage trips. Those controlling the 1,000 h.p. motors are rated at 1,600 amps, while the breakers for the 450 and 350 h.p.

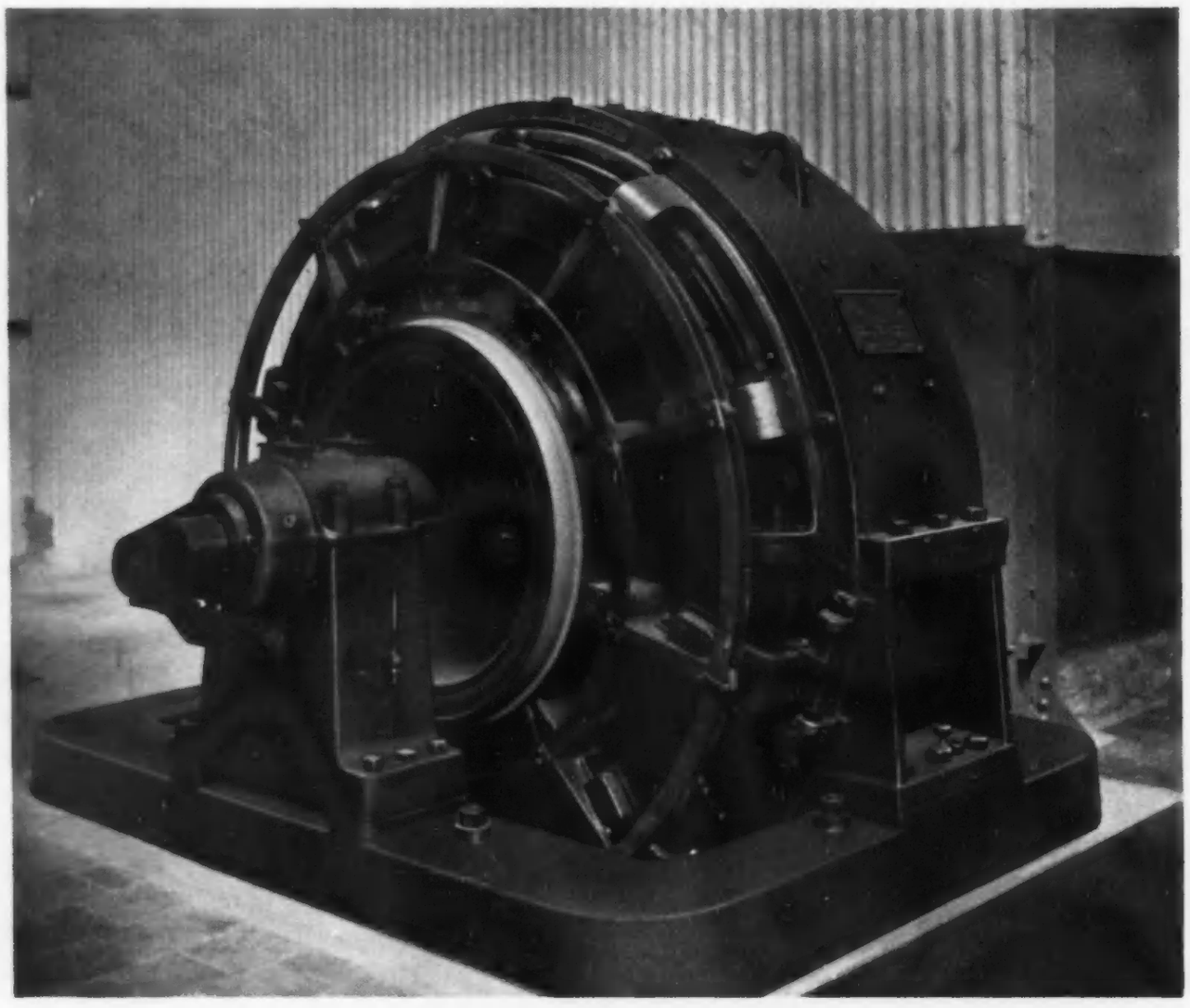


Fig. 7.—1,000 h.p. D.C. motor, 165/500 r.p.m., driving roughing mill.

A diagram of connections of the control scheme is given at fig. 11.

On the incoming panel, a double pole hand operated circuit breaker, of the line-contact type, is mounted, together with a neutral switch and voltmeter. The circuit breaker is provided with overload and under voltage trips, while the neutral switch is so interlocked with the circuit breaker that it cannot be opened if the circuit breaker is closed, neither can the breaker be closed when the neutral switch is open.

The panels controlling the rolling mill motors are similar, and on each are mounted a double pole hand operated line contact circuit breaker, the necessary accelerating contactors, field protective relays, and counter E.M.F. relay. On the panels for the two 1,000 h.p. and the 450 h.p. motors, the last step of the resistance is cut out by a solenoid operated double pole line contact circuit breaker, but for the 350 h.p. motor, a contactor fulfils this service.

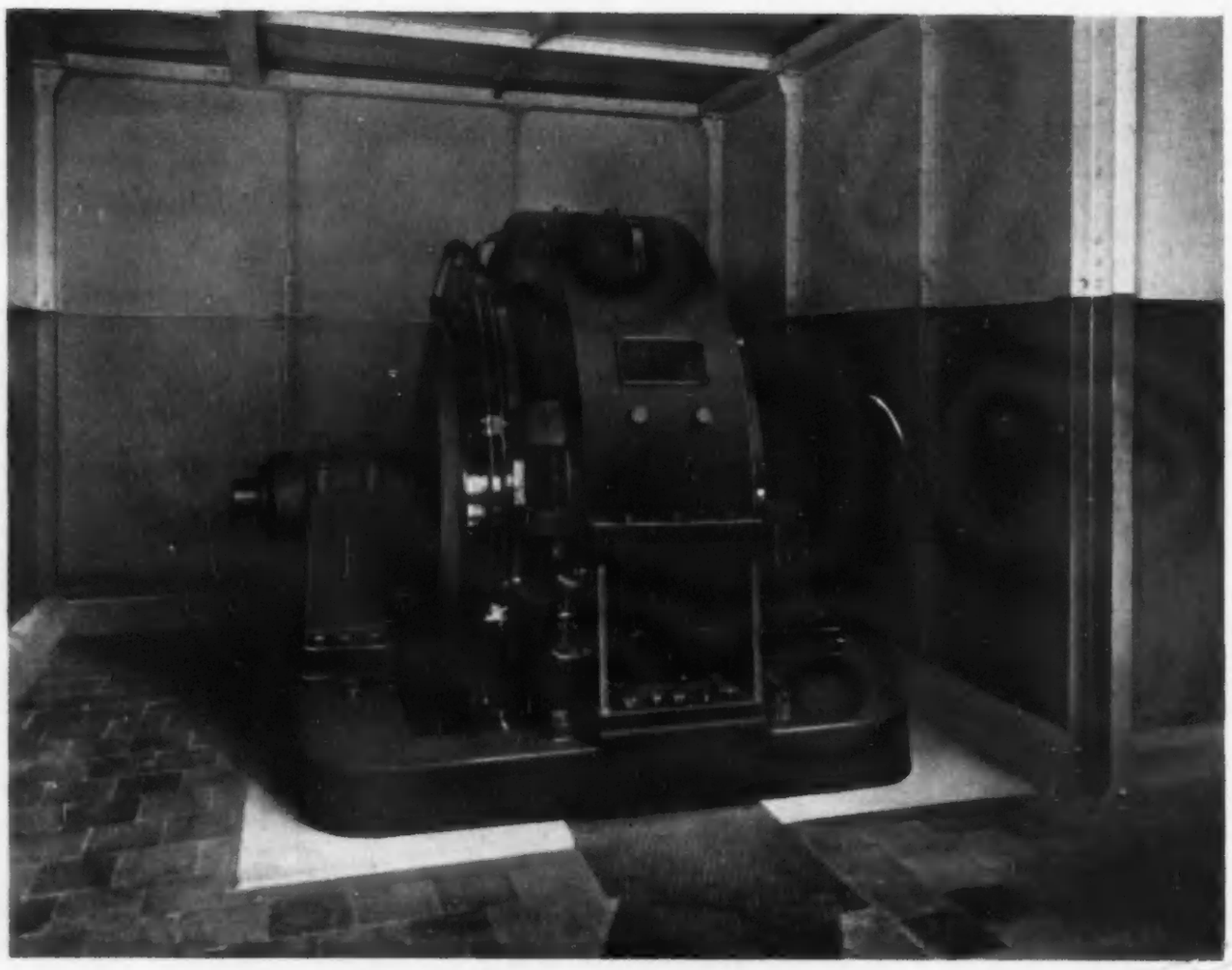


Fig. 8.—Intermediate mill motor, with same capacity and speed range as that shown in fig. 7.

machines will carry 800 amps and 600 amps respectively.

The number of accelerating contactors varies

for the different motors. For the 1,000 h.p. machines 11 accelerating contactors are supplied, while for the smaller motors, this number is decreased to seven. The starting resistances are of the protected type, and are mounted on rolled steel supports behind the switchboard.

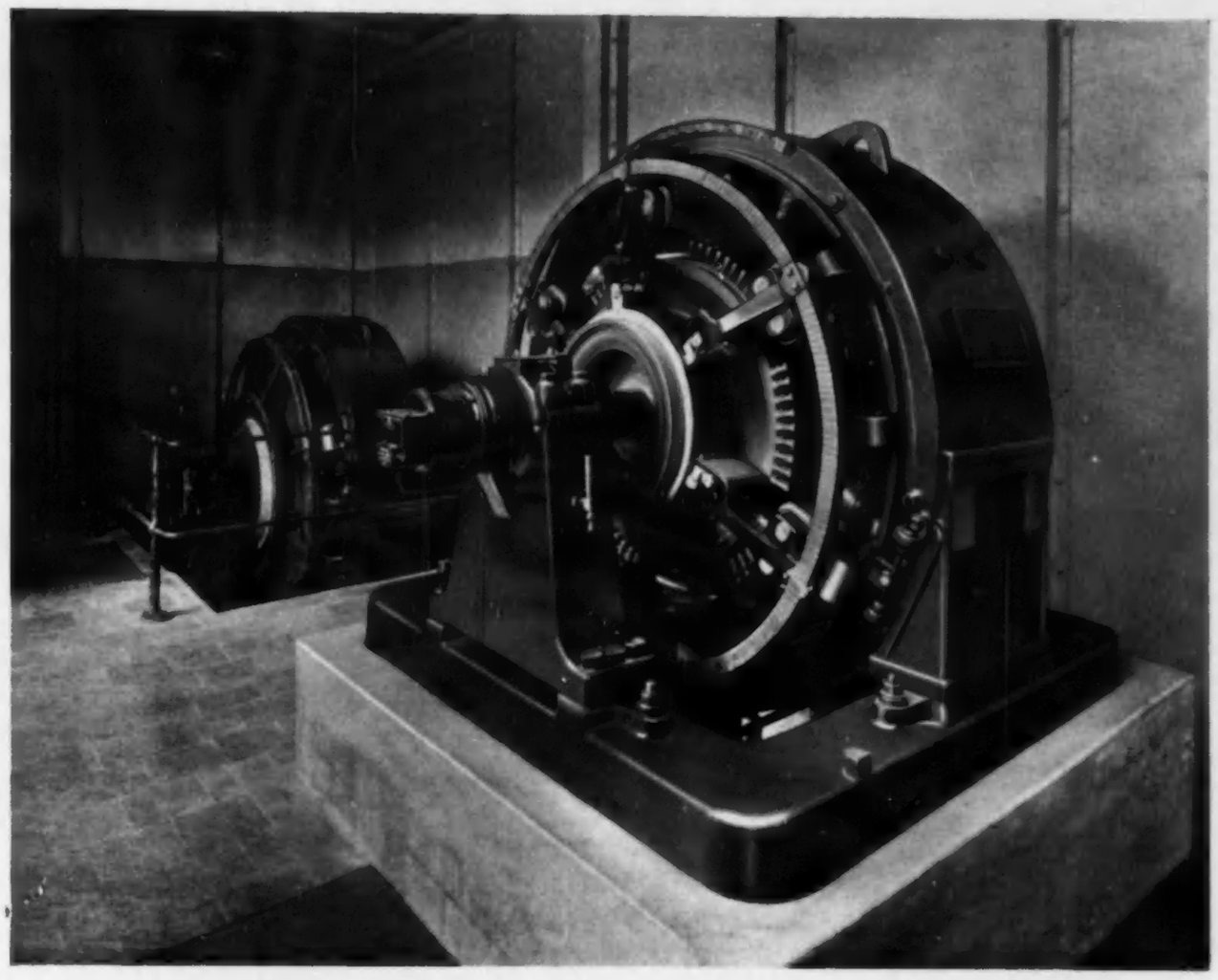


Fig. 9.—350 h.p. and 450 h.p. D.C. motors driving various stands of the finishing mill.

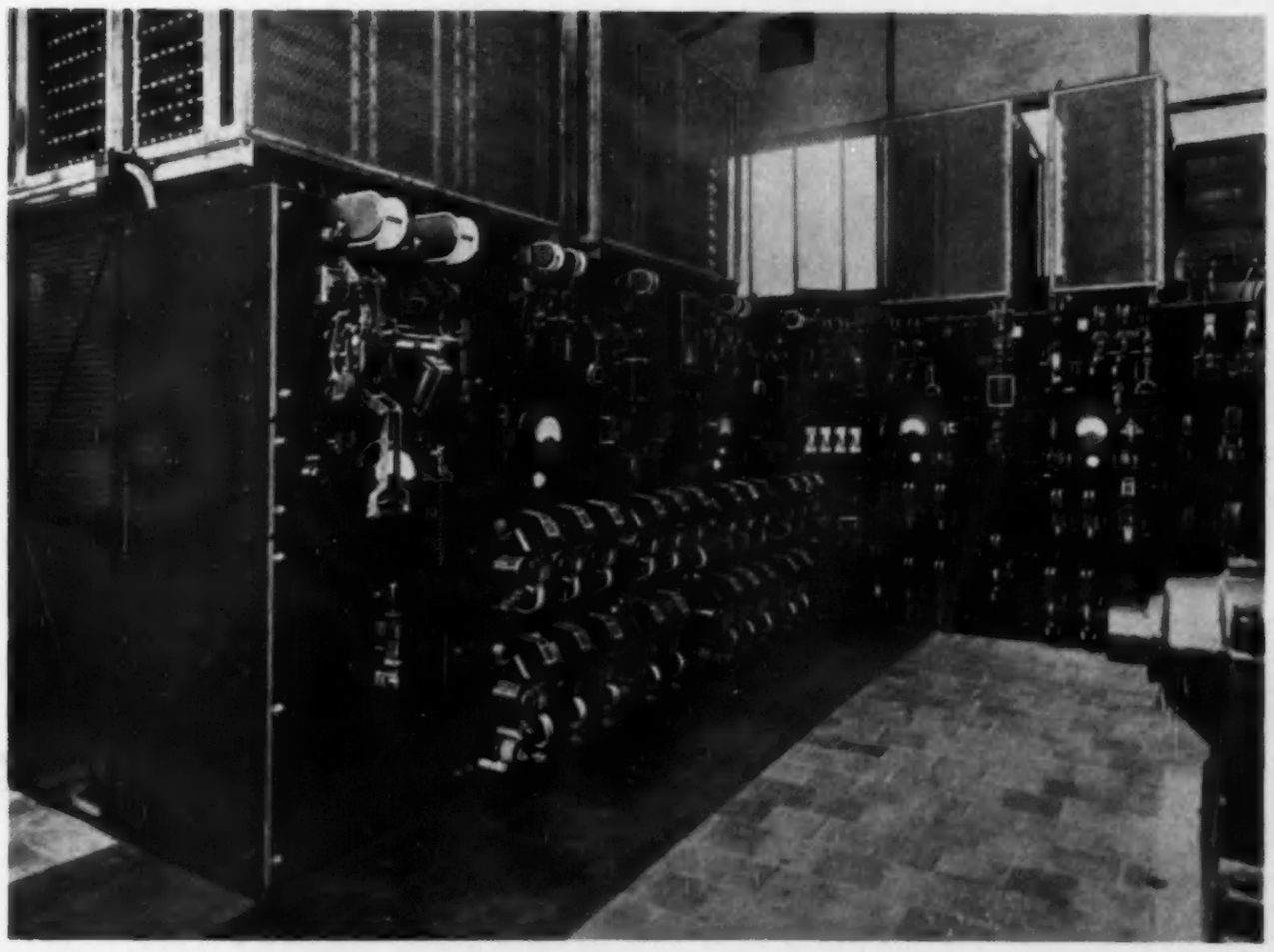


Fig. 10.—Motor control switchboard, with automatic contactor equipment.

A recording watthour meter, mounted on one of the panels controlling the 1,000 h.p. motor which drives the roughing mill, indicates the power consumption of this mill, and is a check on the driver and the operators, while pilot lamps are incorporated on each panel.

The accelerating contactors are remote operated from a 5-panel control desk (fig. 12) which is installed in such a position that the attendant has a clear view of all operations of the mill. The instrument panels are mounted immediately above the control desk, each panel carrying an ammeter and speed indicator. The field change-over switches for reversing the mill motors are mounted close to the control desk ; they are interlocked so that they cannot be operated until the appropriate mill motor has stopped. Each panel of the control desk is equipped with a master controller and shunt regulator. For normal starting conditions the controller is moved to the first notch which provides $\frac{1}{3}$ full load torque on the motor. In the event of the mill being "stiff," a condition likely to occur after a prolonged shut-down, the controller is moved to its third notch which provides twice full load torque on the motor. Provision is also made for the shunt regulators to be left in position so as to give the correct motor speed for any particular rolling operation. For this purpose, vibrating contactor field relays are mounted on the main switchboard

so that when the motors are re-started they automatically attain the correct speed as determined by the positions of the appropriate shunt regulators.

Full protection is provided to safeguard the motors against (1) excessive speed due to failure of the field circuit, and (2) flashover, due to restoration of full field when the motor is running at high speed.

In the event of a complete break in the field system, the motor is automatically stopped, but should a partial failure occur with corresponding weakening of the field, the protective relays safeguard the motors against excessive speed, but do not completely stop the mill. Under these conditions the first accelerating contactor remains in circuit so that the motor current is limited to one third of full load current. In this way the mill can continue to operate at a reduced speed until the hot metal is clear of the rolls, so that jamming and consequent difficulty in re-starting is avoided.

Protection against flash over as a result of full field being restored to the motor while it is still running at a high speed, is provided by a counter E.M.F. relay, which ensures that the shunt field

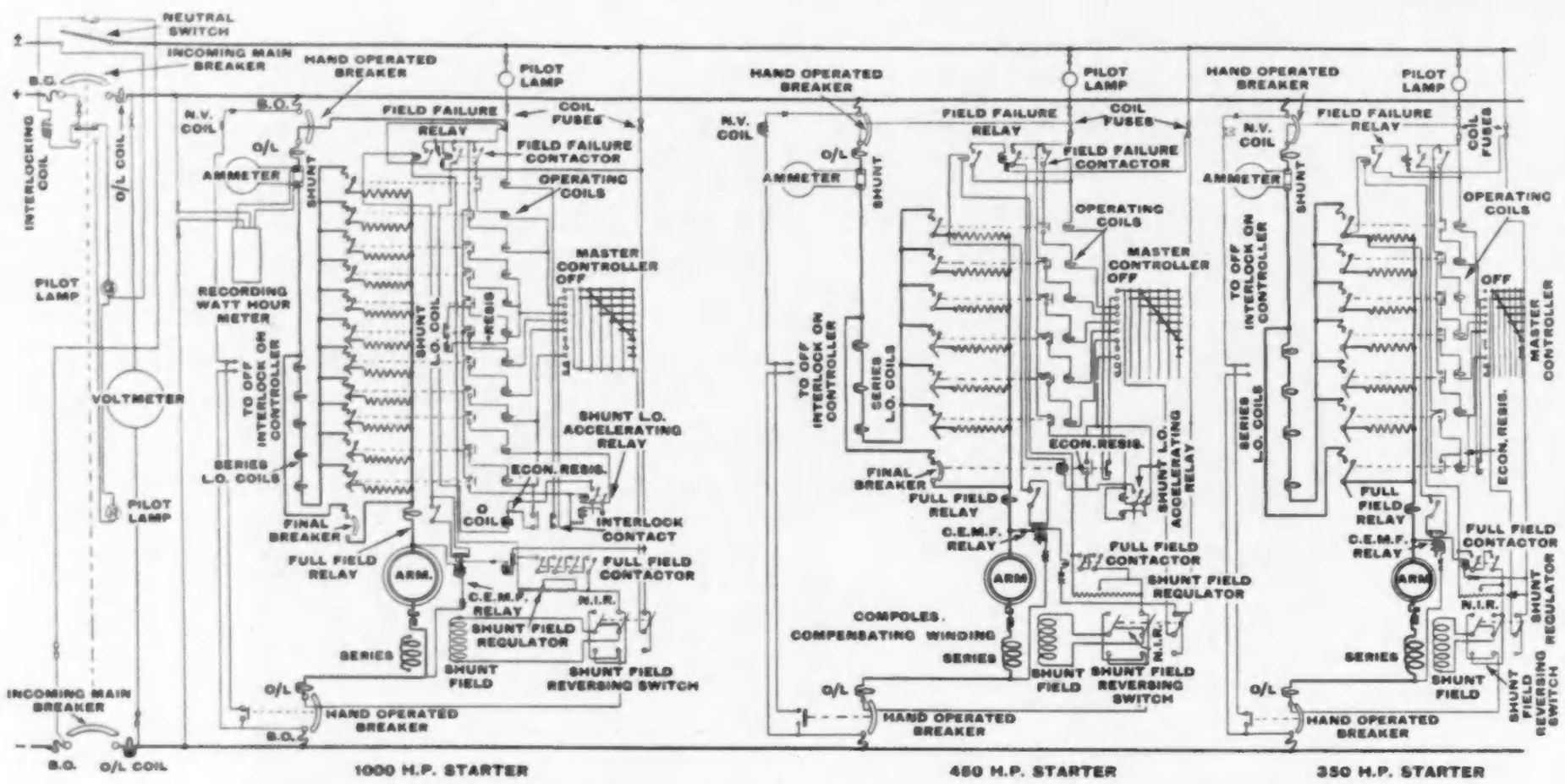


Fig. 11.—Diagram of connections of mill motor control equipment.

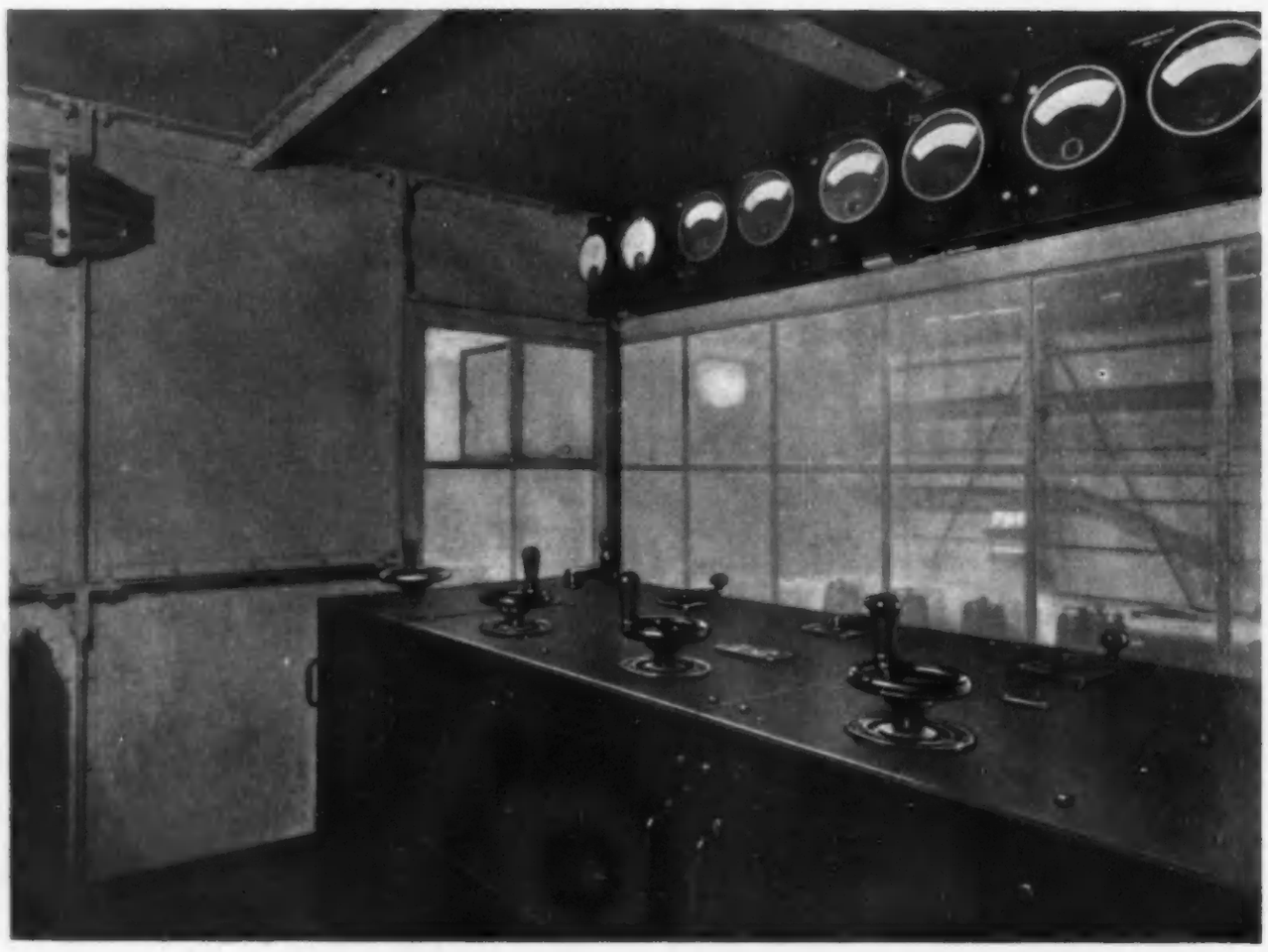


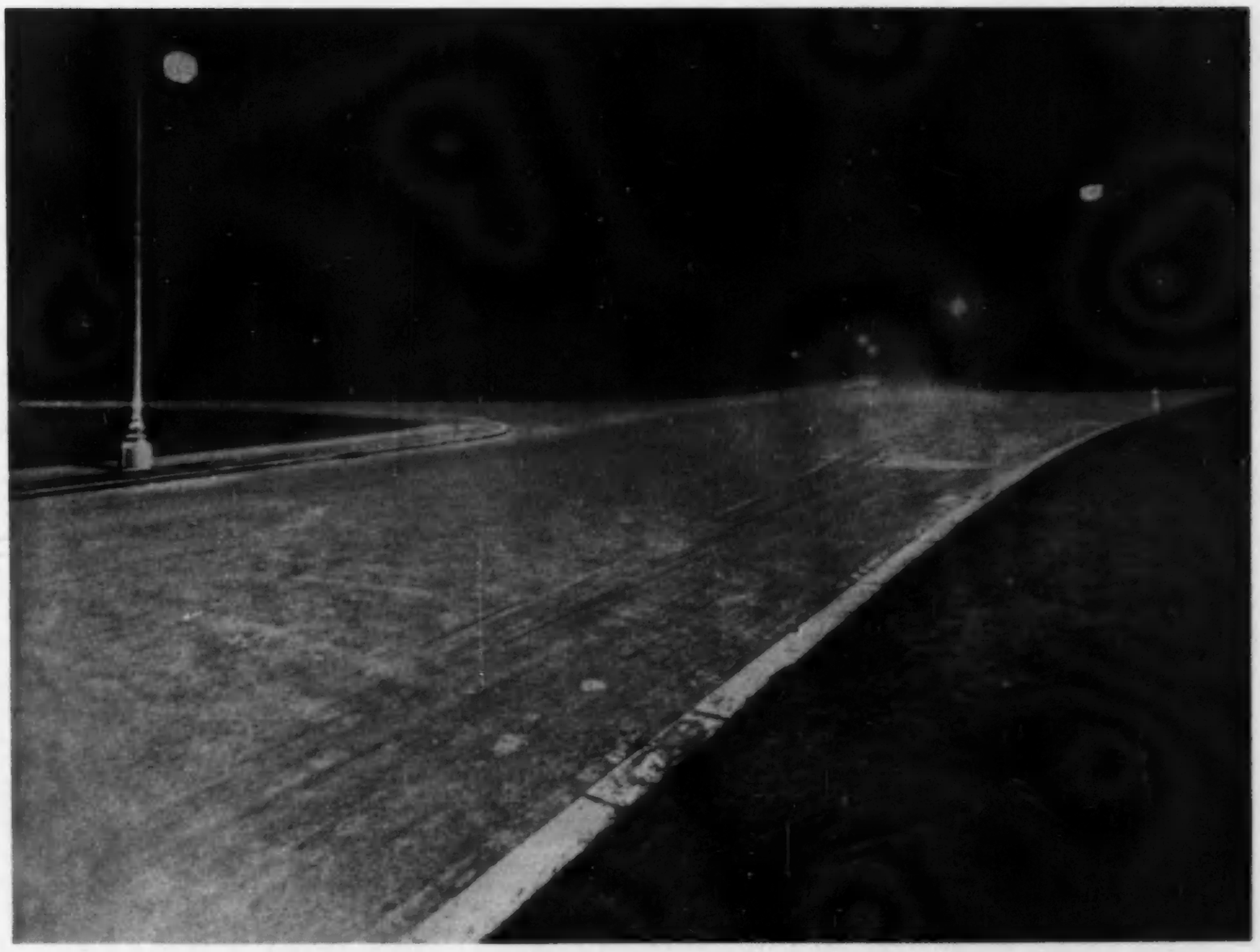
Fig. 12.—Control board, comprising master controllers. Note windows giving clear view of mill.

resistance remains in circuit until the back E.M.F. of the motor has fallen to a predetermined value. Without this relay, any rapid movement of the controller to the "off" position would result in full field being restored on the motor before it had time to lose its speed, which is maintained for a definite time by the inertia of the machine.

It should be added that the electric supply is taken from the 6,600 volt mains of the Newport Corporation and is converted in the company's sub-station to 500 volts D.C. Fig. 13 shows the 1,500 kW rotary converter which was added to the sub-station equipment to provide for the extra demand created by the installation of the new mill.

Fig. 13.—1,500 kW rotary converter in the works sub-station, supplying power to the new mill.

Discharge Lamps for Street Lighting.



Chester-le-Street (Durham) by-pass road illuminated by Osira lamps in Lewisham lanterns.

The Testing of Cinematograph Carbons.

By W. COMPTON TILL, M.Sc., Development Laboratory, Witton Engineering Works,
and FRANK S. HAWKINS, Ph.D., A.I.C., Research Laboratories of The General Electric Co., Ltd., Wembley, England.

The testing of arc-lamp carbons has its own special problems and difficulties. Particularly is this so in the accurate measurement of light output. Unlike most other lamps, the carbon arc is used in such a way that the image of the source is projected, and it is the average intensity of this which has to be measured.

Differences between the colour of the light and that of the standards, and also the movement of the centre of intensity within the arc itself, present special problems in accurate photometry, and the authors describe how these have been overcome.

1. INTRODUCTION.

THE modern cinematograph projector is the direct descendant of the "magic lantern," although the original candle has been replaced by the carbon arc and the optical system has been subject to considerable improvement.

In fig. 1 are shown diagrammatically the two methods of light projection in most general use at the present time. In one method, the light from the positive crater of the arc is collected by means of the condenser C, which concentrates it on an aperture G known as the "gate," consisting of a rectangular opening identical in size with one frame of film, *i.e.*, a little larger than a postage stamp. By means of a suitable driving gear, the film is passed in

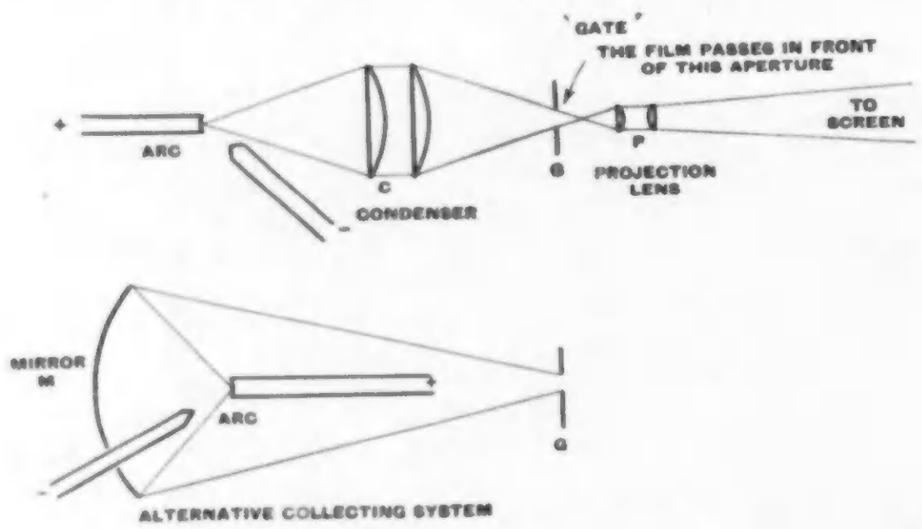


Fig. 1.—Diagram of optical systems used in cinema projectors.

front of the condenser side of the gate ; an image of the illuminated film is thrown on to a white screen by means of the projection lens P, and so is made visible to the audience. The second method of projection differs from the first only in the use of a mirror as a collecting agent in place of a condenser, the arrangement of film, gate and projection lens remaining the same. Combinations of mirrors and condensers may also be used to collect the light from the arc.

It is desirable that the flux reaching the screen should be about 2,000 lumens, and this is roughly equivalent to the total flux emitted by a 200 watt gasfilled tungsten lamp, but the losses in the projector and in the smoky atmosphere of the cinema are so great that a very powerful source of illumination is required.

It has been estimated that of the light generated in the projector lamphouse, not more than 3 per cent reaches the screen, and of this only two-thirds is reflected back into the auditorium. To ensure satisfactory screen illumination, therefore, arcs dissipating as much as 10 kilowatts may have to be installed. Until comparatively recently the chief sources of illumination were low intensity direct current arcs of either the mirror or condenser type, and these are still largely used in the smaller houses. In the case of the larger cinemas, however, light losses are accentuated by the long throw, and in addition the use of perforated screens (behind which loud speakers are placed) results in loss of reflective power. Consequently in theatres of this nature the low intensity arc has been supplanted by the high intensity D.C. arc.

2. TYPES OF ARC USED.

(*a*) *Low Intensity or "Mirror" Arc.*

The low intensity arc (fig. 2) burns cored positive and negative carbons. It was first used in lamps in which the carbons were aligned at 180° to each other, and were inclined at a small angle to the vertical. The light was collected by means of a condenser, but this system was found to be less efficient than one in which the positive carbon was set in the horizontal plane, while the negative was aligned at a convenient angle, the light being then collected by means of a mirror. The latter type of lamp became so popular that the carbons it burns are universally known as "mirror arc carbons." The positive for such a lamp is a carbon rod from 8-14 mm. in diameter and 8-12 inches long, made with an axial core hole whose diameter is about one-third to one-quarter the diameter of the carbon. This core is filled with a dried paste made of carbon powder and water-glass, the object of which is to steady the arc.

The negative carbon is an annular carbon rod similar to the positive, but it is cored with a solid rod of carbon which has been plated with copper 0.05 mm. thick. The core is so coated with copper

to increase the conductivity of the carbon, thereby enabling it to function at a higher current density without overheating. By this means it is possible to use a negative which is smaller in diameter than the positive, and as the incandescent positive crater is the main source of light, such a negative increases the effective light output of the arc by causing less obscuration of the positive crater.

(*b*) *High Intensity Arc.*

The high intensity arc, fig. 3, differs fundamentally from the low intensity in that the main source of light is not an incandescent carbon surface, but a mass of glowing vapour. The positive carbon contains a comparatively large core whose diameter is half that of the positive shell; at least 50 per cent of its weight consists of rare earth compounds. The negative carbon is similar to the low intensity negative.

3. THEORY OF OPERATION OF THE ARC.

It is not possible in the space available to go deeply into the theory of how the arc operates; in any case some of the theory is still of a controversial nature. What follows must therefore be taken to be only a rough picture, which approximates sufficiently to the truth to convey a working notion.

(*a*) *The Low Intensity Arc.*

The arc is struck by applying a potential difference of about 80 volts across the two electrodes,

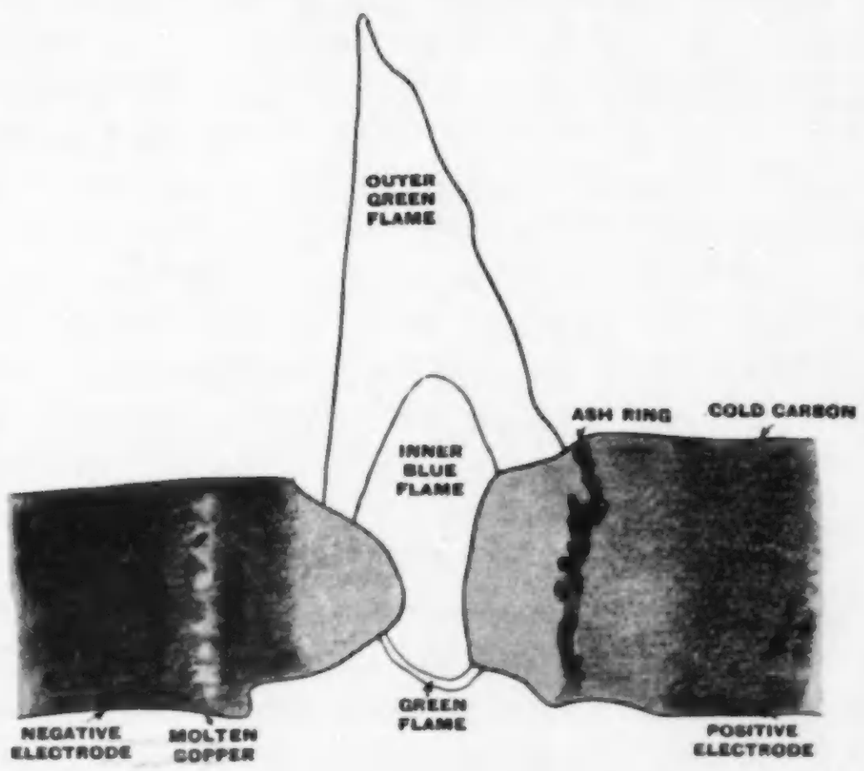


Fig. 2.—Normal low intensity arc.

allowing them to touch and then separating them. At the moment of touching, the heat generated by the passage of the current heats a small area of the negative carbon, and causes a thermionic emission of electrons therefrom. Under the influence of the potential gradient, the electrons are driven towards the positive electrode, which is heated by their bombardment to the sublimation temperature of carbon. The electron stream also collides with and so ionizes the molecules of the gases and vapours found in the space between the electrodes, and the positive and negative ions thus formed bombard the negative and positive electrodes respectively, thereby keeping them at a white heat and maintaining the arc. As the sublimation temperature of carbon is high (3,500° to 4,000°k) the crater formed in the positive carbon emits a dazzling white light, and this is the source of the light used in the projector.

(*b*) *The High Intensity Arc.*

When this arc is struck the electrodes are maintained at a high temperature by the mechanism

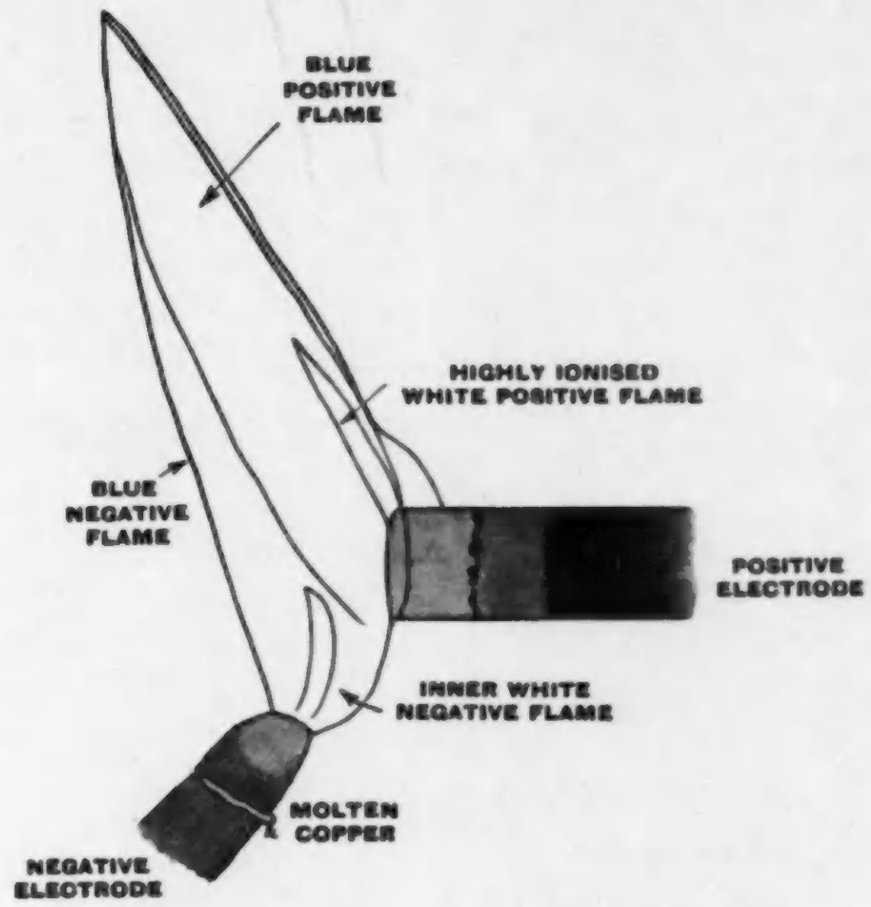


Fig. 3.—Normal high intensity arc.

previously described, but at current densities greater than 70 amps sq. cm., the positive core is volatilized more readily than the shell, and so forms a deep crater which is filled with the glowing gaseous core material. This emits an extremely brilliant white light (Table 1), which is the source of the screen illumination.

TABLE 1.

INTRINSIC BRIGHTNESS OF DIFFERENT LIGHT SOURCES.

Light Source.	Brightness in Candles/sq. mm.
High Intensity arc[1]	500 – 1000
Low Intensity arc[2]	1/2
Tungsten Filament Lamp[3] ..	1 – 13

To utilize this arc as efficiently as possible, the crater must be kept brimfull of incandescent gas, and this is accomplished by so positioning the negative electrode that the stream of negatively charged matter impinges on the positive crater and hinders the escape of the luminous gas. The positive is prevented from burning with an uneven edge or lip either by rotating it, or by deflecting the

1. P. R. Bassett. Trans. I.E.S., 1932, **27**. 624.
2. N. A. Allen. El. Rev., 1923, **23**, 238.
3. Forsythe and Worthing. Astrophys. J., 1925, **61**, 146. Also Jones and Langmuir, G.E. Review, 1927, p. 310.

arc stream along the axis of the positive carbon by the application of a magnetic field.

4. TYPES OF TEST.

The cinema projector requires a source of light which is steady in intensity, white in colour, and sufficiently powerful to provide a screen illumination of not less than 3 ft.-candles, measured when the projector is running, but without film in the machine. Consequently tests are required which yield information on these three points, as well as on the rate of consumption of the carbons.

5. THE DETERMINATION OF SCREEN ILLUMINATION.

The screen illumination produced by a pair of carbons is generally considered to be their most important property, and so requires to be accurately measured. There are, however, certain inherent difficulties in this measurement, for the illumination is particularly sensitive to changes in the burning conditions, *e.g.*, changes in arc length, current through the arc, and small changes in the focussing of the light on to the film aperture, or "gate" which may be caused by any slight irregularity in the burning rate of the carbons. In order to obtain the best results it is essential that these factors should be carefully regulated. Even when all these variables are controlled there still remain variations in the light intensity due to small changes in the formation of the crater, for even under the best burning conditions, no carbon will form a crater which does not change its shape slightly while the carbon is burning away, the extent of the change varying with the type of carbon, the lamp in which it is burnt, and the operator who adjusts the lamp.

Another difficulty in the photometry of the carbon arc is the difference in colour which is found between the light from the arc and that from the standard lamps with which the arc light is compared. The colour of the light of the low intensity arc approximates to that of a black body radiating at 3,500—4,000°K. whilst the light from the high intensity arc approximates to a body radiating at a much higher temperatutre. It is markedly bluish white in colour when compared with the light from tungsten filament lamps.

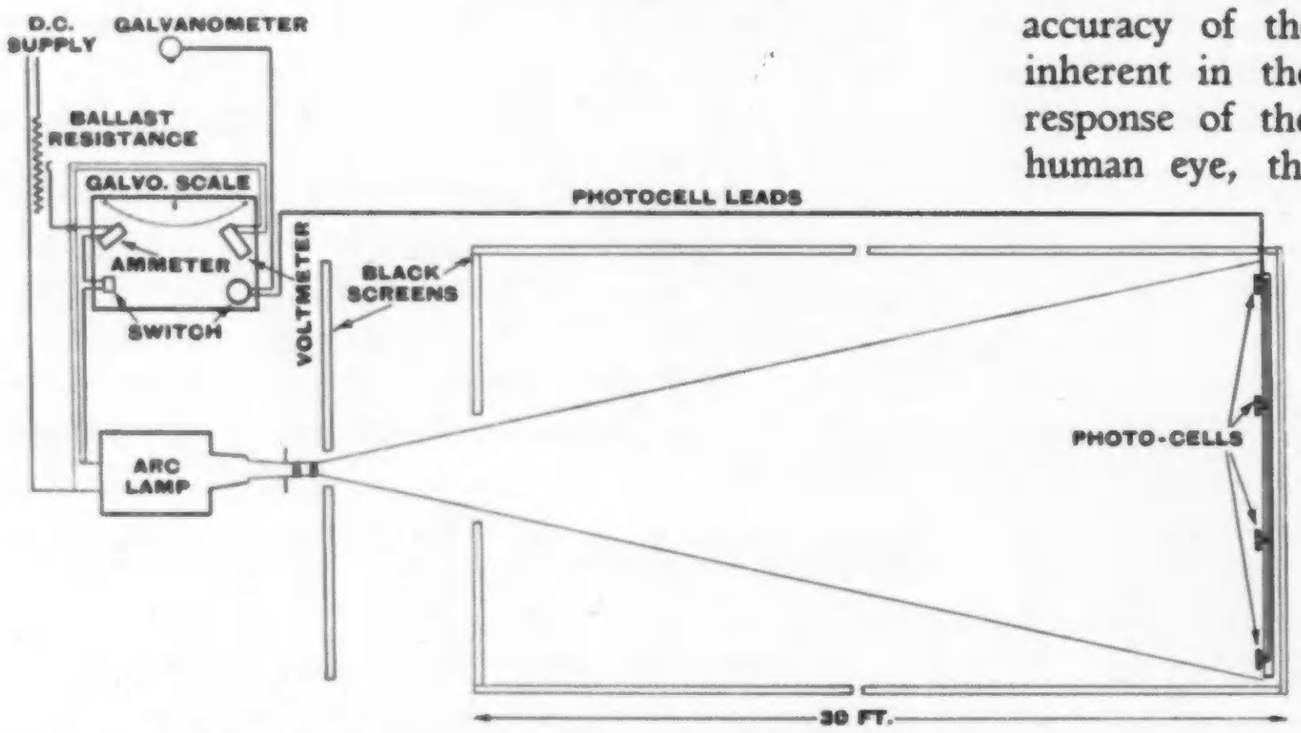


Fig. 4.—Diagrammatic arrangement of cinema arc photometer, showing electrical connections.

6. THE METHODS AVAILABLE FOR MEASUREMENT OF SCREEN ILLUMINATION.

There are two methods available for the determination of screen illumination ; namely the visual comparison of the illumination with that given by tungsten filament standard lamps using a suitable photometer head, and the measurement of the response of a photo-electric cell illuminated by the arc in the same way as is the screen. The former method suffers from two disadvantages which reduce its accuracy ; the difference in colour between the arc light and the light of the standard lamp, and the variations of the arc light, both of which render it difficult to balance the brightnesses of the two fields visible in the photometer head. It is possible to minimise the first of these errors by having several observers, and the second by each observer taking several readings, but such a procedure is both slow and cumbersome, and so unsuitable for routine use.

On the other hand, if the response of a photo-cell be used to measure the screen illumination, the accuracy of the results is limited by the errors inherent in the cell. For instance, the spectral response of the cell may differ from that of the human eye, thus making the photo-electric effect a function of the colour as well as of the intensity of the light. Moreover, the cell may fatigue and respond more feebly after prolonged illumination, or its response may change with temperature. Nevertheless, a photocell has the advantages that its response can be measured directly by means of a suitable galvanometer, it follows any change in the intensity of the light incident upon it almost instantaneously, and its use eliminates the awkward operation of balancing in a visual photometer head two lights of different colour, one of which is somewhat variable in intensity. Hence, provided that the sources of error mentioned can be eliminated or sufficiently minimised, the photo-cell furnishes a convenient means of measuring screen illuminations.

7. THE CALIBRATION OF A SUITABLE PHOTO-CELL.

If a photo-cell be used for measurement of screen illumination the errors due to change in temperature

and fatigue of the cell can be minimised by avoiding temperature change, and prolonged exposure of the cell to light, but it is necessary that the spectral response of the cell used should be similar to that of the human eye, otherwise small changes in the colour of the light will cause large errors in the

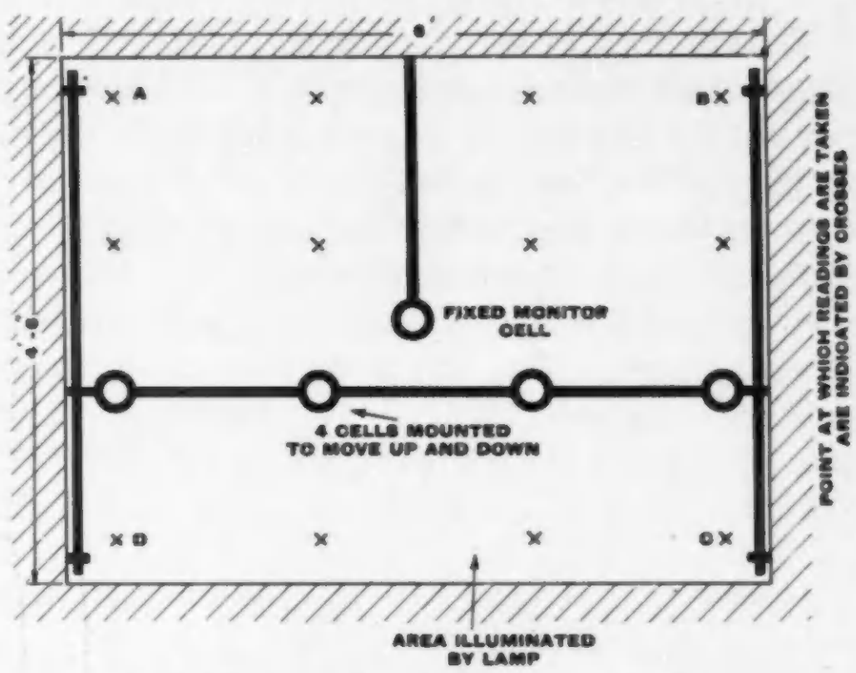


Fig. 5.—Diagram showing layout of photocells.

measurement of illumination. As no data were available concerning the response of photo-cells to the light of a cinematograph projector, it was found necessary to make a direct comparison between the response of the photo-cell and the illumination, measuring the latter with a precision visual photometer and using the mean of the observations of several observers in the manner previously outlined.

The results of these tests showed that a particular kind of selenium rectifier cell had a response which agreed with the visual observations within ± 3 per cent when used for the specific purpose for which it was required, namely, the comparison in the same arc lamp of carbons, similar in type but differing in the manner in which they were made. It was therefore used in the construction of the photometer described in the following paragraphs.

8. THE APPARATUS USED FOR MEASUREMENT OF SCREEN ILLUMINATIONS.

(*a*) *The Lamps and Control Table.*

The layout of the photometer used for the measurement of screen illuminations at the Research Laboratories of the G.E.C. is shown in figs. 4, 5 and 6. It consists of a space 30 ft. × 6 ft. × 8ft., permanently darkened by suitable screening, which has at one end the lamps with their projector heads and the control table, and at the other end the photocells. Any one lamp can be wheeled into its correct position and is temporarily fixed there by means of bolts let into the floor. These are so arranged that when any lamp is bolted down it automatically takes up the correct position for projecting its light on to the photo-cells, which are placed where the screen is normally found. The control table carries an ammeter and voltmeter (connected in series with the arc, and across the arc gap respectively), the necessary switchgear and two galvanometers with their scales, which register the current generated by the photo-cells, and are calibrated to read directly in foot-candles. A continuously variable ballasting resistance which allows the arc current to be varied between 15 and 150 amps. is fixed on the left hand side of the control table, and periscopes are fitted to each of the lamps throwing an image of the arc on to a small white screen on the right of the table. By means of this device any change in the position of the arc and consequent change in the focussing of the lamp can be seen and corrected. The lamps themselves are placed close to the table, and the layout is arranged in such a manner that one operator sitting at the table has complete control of the burning of the arc and the measurements of its screen illumination. By this means the many variables which may affect the screen illumination given by an arc are kept

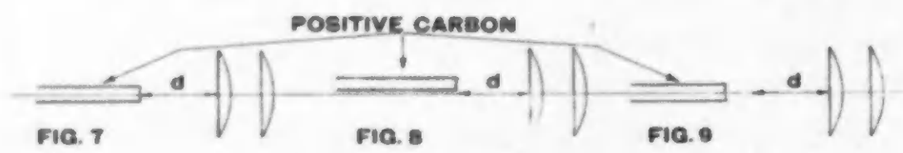
Fig. 6.—Carbon arc photometer control table.

rigidly in check and comparative tests between different carbons can be made with the highest available accuracy.

(*b*) *The Photo Cells.*

The beam of light projected by the arc lamps would form a rectangular picture 6 ft. × 4 ft. 6 in. when it reaches the photocells (fig. 5), and to obtain a satisfactory mean value of the screen illumination

it is necessary to measure its value at several points and so determine the distribution of the illumination over the beam. This is necessary as the distribution can be affected by the design of the carbon and it is not desirable to illuminate the screen brightly at the centre and dimly at the edges. These measurements are made by the use of five photocells in the



Figs. 7, 8 and 9.—Illustrating the necessity of having the carbon crater coincident with the optical axis and at a certain distance from the mirror or condenser.

following manner. Four of these cells are mounted on a bar which can be raised or lowered so that the cells can be placed in any part of the beam (fig. 5), while the fifth remains fixed at the centre. The four cells mounted on the bar can be connected, one at a time, by a suitable switch to a galvanometer and are used to explore the beam and so to measure the distribution of the illumination therefrom. If the arc were perfectly steady, a true picture of the distribution could be obtained by taking consecutive readings of these cells in different places in the beam, but unfortunately the illumination given by an arc is never quite

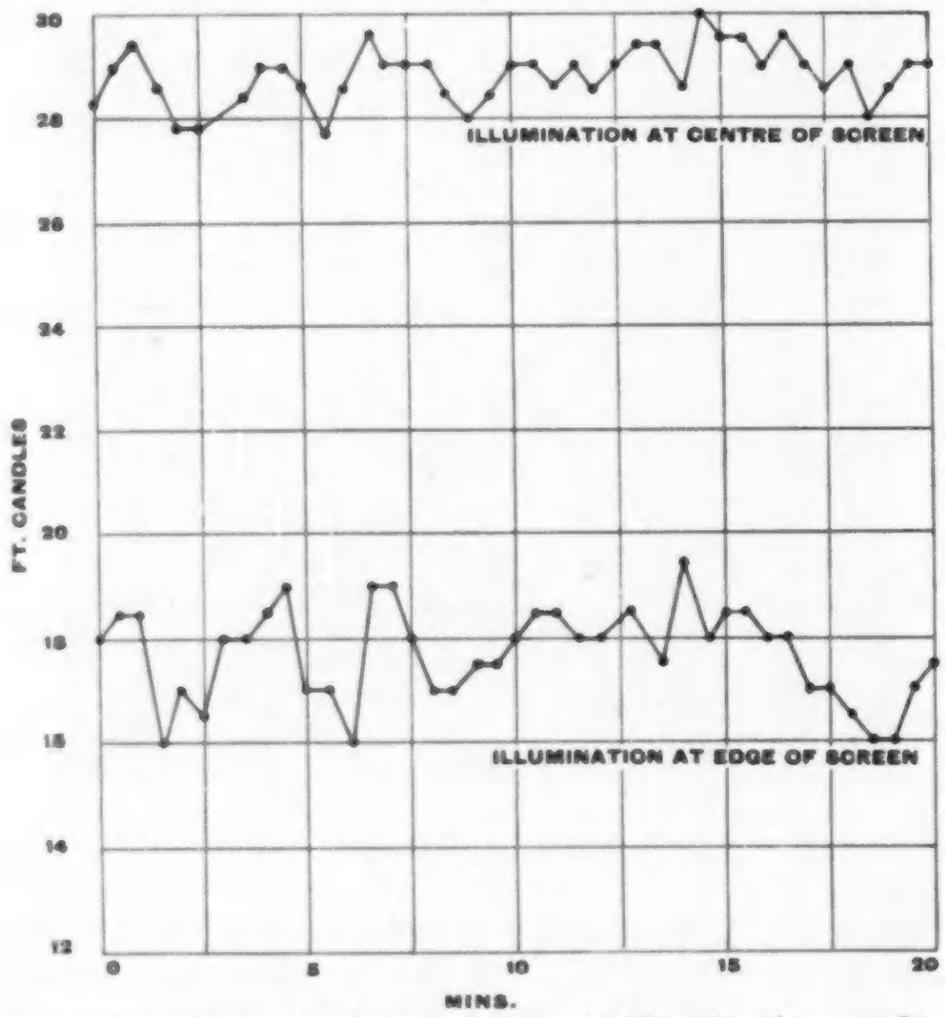


Fig. 10.—Chart showing variations in illumination at edge and centre of screen.

constant; it usually undergoes an irregular periodic change and it is therefore necessary to ensure that the variations which occur with the passage of time are not a source of error in the measurement of the distribution of the illumination. This is achieved by means of the central fixed cell which is connected to a separate galvanometer and acts as a monitor cell in the manner described below.

9. THE METHOD OF DETERMINING THE MEAN SCREEN ILLUMINATION.

The method used for determining the mean screen illumination is as follows.—The various lenses in the projector are carefully cleaned, and then the pair of carbons to be tested is inserted in the lamp and burned at their rated current for 10 minutes, *i.e.*, until the electrode tips have burnt to their normal shape. The focussing of the lamp is then adjusted. As the optical system of the lamp is symmetrical about its axis, the system is correctly focussed when the centre of the positive crater is coincident with the optical axis, and at a certain

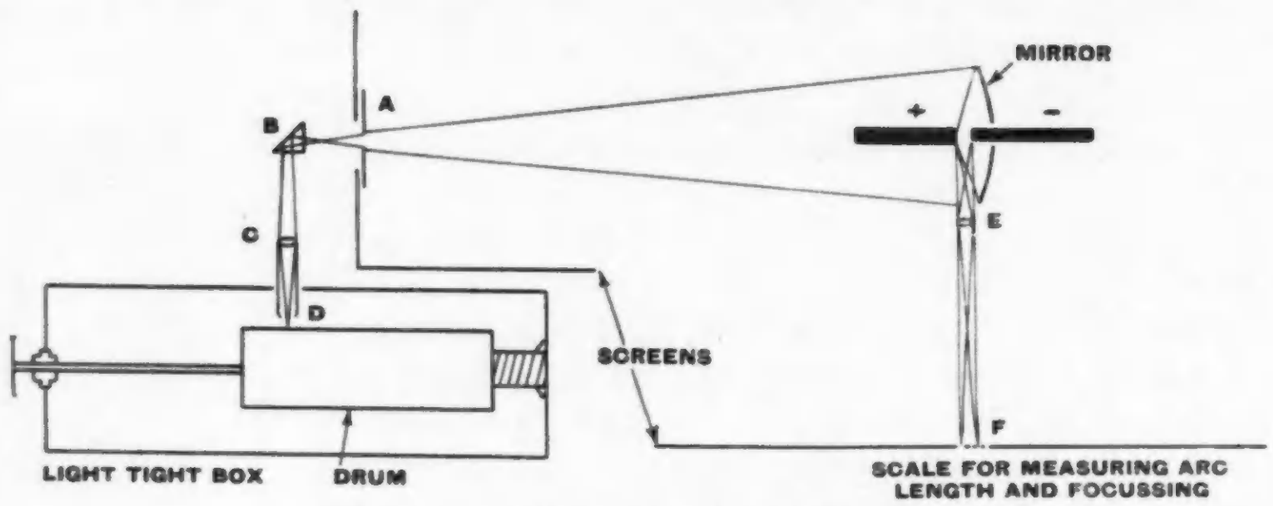


Fig. 11.—Diagram of flicker recorder.

distance, d, from the mirror or condenser, determined by its focal length and the position of the gate (fig. 7). If the crater centre is off the optical axis (fig. 8), the illumination of the screen will be unsymmetrical, the brightest spot will not be at the middle, and so the illumination at four points A, B, C, D, equidistant from the centre (fig. 5), will not be equal. Similarly if the crater centre is coincident with the axis, but not at the correct distance from the mirror or condenser (fig. 9), the screen illumination will not be at its maximum. In practice the arc in a cinema projector may be found to be out of focus for either or both of these reasons, but it can be corrected by first adjusting it until a photo-cell placed in positions A, B, C, D (fig. 5), gives the same reading, and then racking the arc backwards or forwards along the optical axis until the illuminations of one corner, *e.g.*, A, and the centre are both at a maximum.

The lamp being correctly set, the screen illumination can now be measured. The response of the central monitor cell is first observed at intervals of half a minute. Its readings change with time, as a result of the irregular periodic changes in the illumination given by the arc, and so are continued until their average value changes by less than 5 per cent. Readings are then taken at sixteen different points within the beam (fig. 5) by means of the

four movable cells, only when the monitor cell shows the illumination of the centre beam to be within $\pm 2\frac{1}{2}$ per cent of its average value. As it has been found (fig. 10) that generally the periodic changes occur in the same sense all over the screen, *i.e.*, if the centre brightens the edges brighten too, the sixteen readings give the most accurate values of the distribution of the illumination at its mean time value, consequently if they be averaged, the resultant figure represents an average value of the variations of the illumination which occur in both space and time, and so is called the mean screen illumination. Examples of mean screen illuminations determined in this way are given in Tables 2, 3 and 4.

TABLE 2.

MEAN SCREEN ILLUMINATIONS OF DIFFERENT CARBONS OF THE SAME MAKE.

(13.6 mm. H.I. Lamp).

Carbon No.	Batch 1.	Batch 2.	Batch 3.
1	22.1 ft. candles	22.3 ft. candles	22.3 ft. candles
2	22.1 ,,	22.1 ,,	22.3 ,,
3	21.3 ,,	21.7 ,,	22.7 ,,
4	22.5 ,,	22.4 ,,	22.9 ,,

TABLE 3.

MEAN SCREEN ILLUMINATIONS OBTAINED BY REPEATED MEASUREMENT OF THE SAME CARBON.

(11 mm. H.I. Lamp).

	Carbon No. 1.	Carbon No. 2.	Carbon No. 3.
1st Test	19.9 ft. candles	18.6 ft. candles	18.2 ft. candles
2nd ,,	18.7 ,,	18.4 ,,	18.2 ,,
3rd ,,	18.5 ,,	18.2 ,,	17.6 ,,

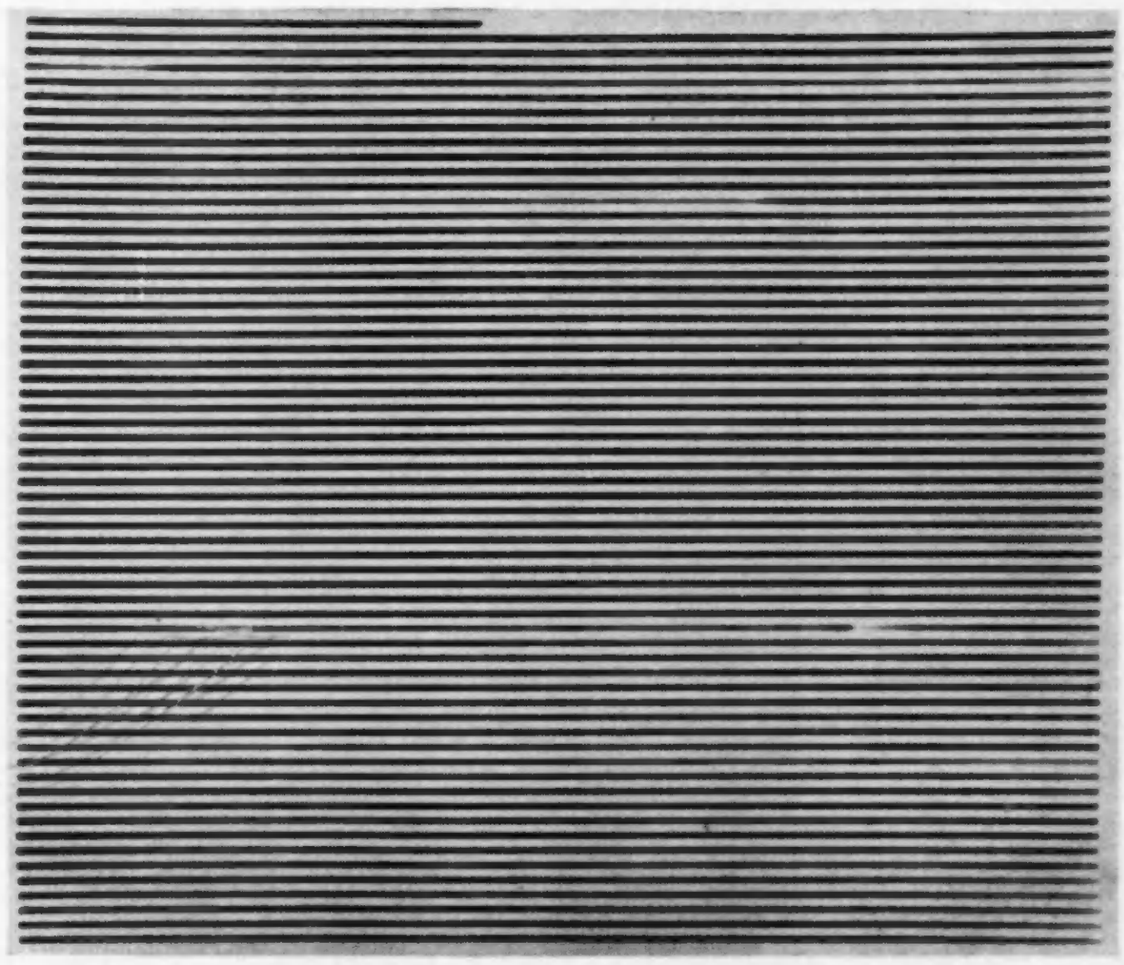


Fig. 12.—Typical record obtained during a steadiness test.

10. THE EVALUATION OF STEADINESS.

The light from an arc is never perfectly steady in intensity; in the high intensity arc the ball of luminous vapour is never still, and the low intensity arc is liable to flicker, *i.e.*, the crater brightness drops suddenly almost to zero and then after a fraction of a second recovers to its normal value. It was found to be difficult to study such transitory effects visually, and a method of recording them has been developed.

TABLE 4.

SPECIMEN RESULT OF MEASUREMENT OF DISTRIBUTION OF SCREEN ILLUMINATION.

17.1 ×	19.2 ×	19.1 ×	16.8 ×
17.6 ×	19.8 ×	19.7 ×	17.5 ×
17.7 ×	19.6 ×	19.5 ×	17.6 ×
17.0 ×	19.0 ×	19.0 ×	17.0 ×

The figures represent the illumination in foot candles at the point marked by the adjacent cross.

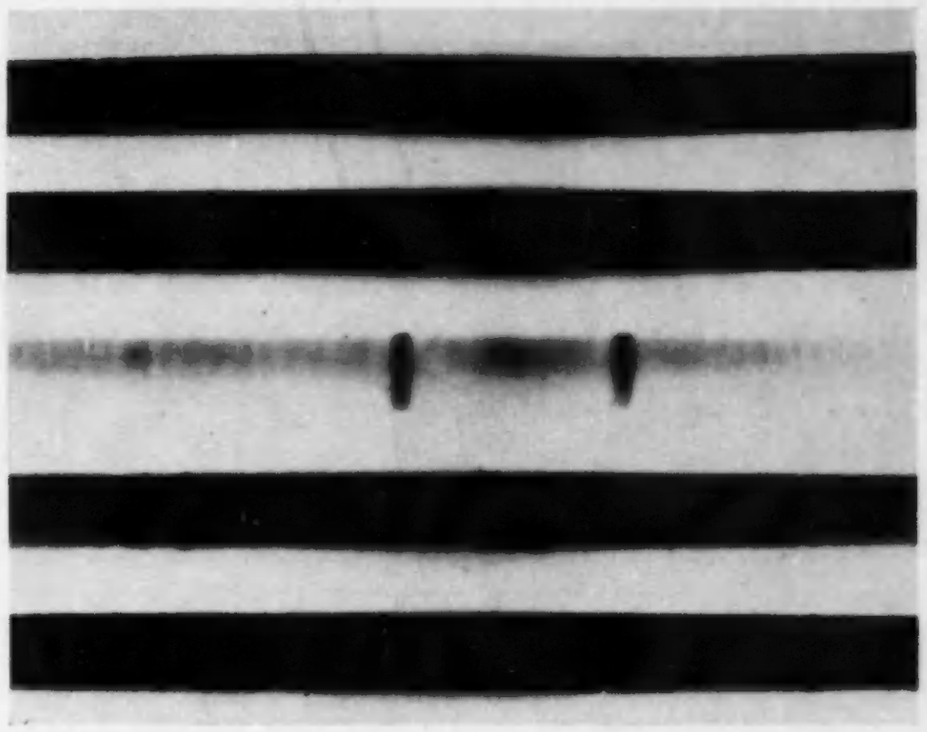


Fig. 13.—Enlarged portion of a steadiness record.

11. THE PHOTOGRAPHIC "FLICKER" RECORDER.

After preliminary trials of other methods, photographic recording of the intensity of the light was found to be the most convenient.

The light from the arc is focussed by means of a mirror on to a slit A (fig. 11) which occupies the place usually taken by the "gate". An image of this slit is focussed by means of the lens C on to the drum D. A piece of bromide paper is wrapped around this drum, which is rotated at a constant speed and driven longitudinally by means of a lead screw, so that the image falling on it traces out a spiral path. If the arc were perfectly steady, the brightness of the slit image would remain constant, and so a series of uniform grey black strips would be obtained after removal and development of the paper. If, however, the arc is unsteady the corresponding changes in the brightness of the slit image will cause lighter and darker patches to appear in the otherwise

uniform strip, and in this way a permanent record of the behaviour of the arc is obtained which can be examined at leisure. Examples of the photographs obtained are given in figs. 12 and 13. The record of a complete test is shown in fig. 12, while fig. 13, which is an enlargement of part of a complete photograph, shows two disturbances, each of which

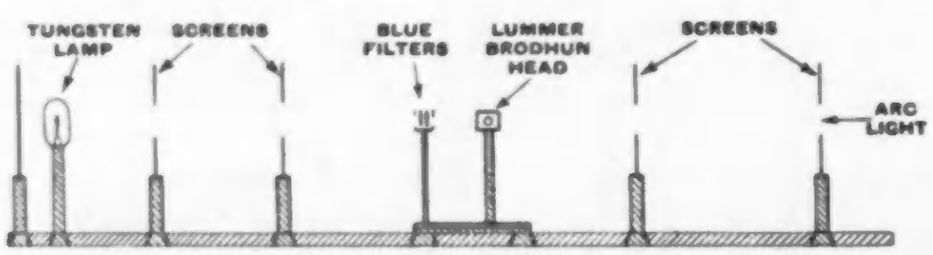


Fig. 14.—Diagram of colour comparator.

results in a sharp increase in crater brightness, and neither of which were of more than $\frac{1}{50}$th second duration. These disturbances were found to be very difficult to distinguish visually.

12. THE COMPARISON OF THE COLOUR OF DIFFERENT ARC LIGHTS.

The colour of the light given by the positive crater of the low intensity arc is governed almost entirely by its temperature, and is therefore liable

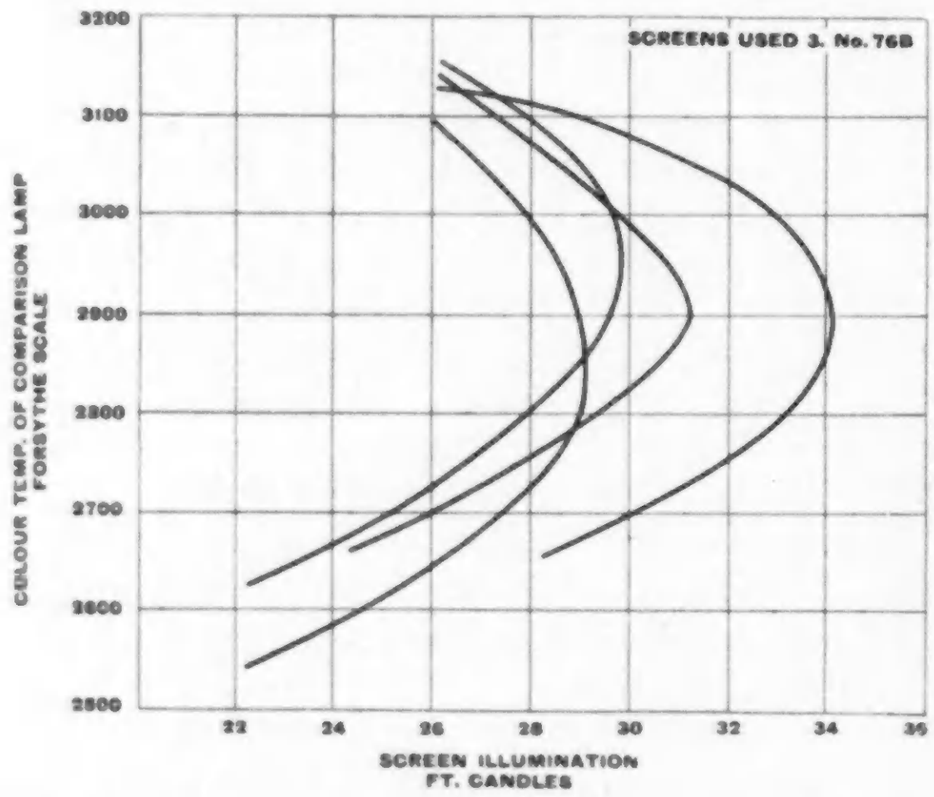


Fig. 15.—Comparison of colour of light thrown on the screen by different carbons.

to suffer only small variations, as the sublimation temperature of carbon is practically constant under normal atmospheric conditions. The high intensity arc, however, differs from the low intensity in that some of its light is furnished by line spectra emitted by its core constituents, and by changing the latter, quite marked changes in the colour of the light can be effected. In order that these changes might be studied, the apparatus illustrated in fig. 14 was used for the purpose of comparing the colours of different arc lights.

It consists of a photometer bench, equipped with a Lummer-Brodhun photometer head, one side of which is illuminated by the arc under examination, the other side by a tungsten filament lamp. The light from the latter which falls on to the photometer head is altered in colour until it matches the arc by placing one or more blue filters in its path, and by varying the amount of current passing through the tungsten lamp. At the same time as the colour of the light from the comparison lamp is changed, the relative distances between the photometer head and the two light sources are also changed so that the brightnesses of the two fields visible in the head remain equal. It is eventually possible to match both the colour and the brightnesses of the two fields, and when this has been achieved the colour can be defined by the number of filters used and the colour temperature of the lamp at balance point, and so can be reproduced for comparison with another arc.

These measurements are complicated by the fact that the colour of the beam of light furnished by a cinema projector is changed by a very small change in the focussing of the arc. In front of the crater of the high intensity arc is a blue flame; the crater itself is white, while the carbon behind the crater is comparatively cool and so emits a light which is brown in colour compared with that of the crater; consequently a blue beam can be obtained by placing the arc flame in the focus of the optical system, and the colour can be changed to white and then to brown by altering the position of the arc.

What is required is the colour of the light when the crater is in focus, and this is found by taking simultaneous measurements of the colour and the screen illumination, as the latter is a maximum when the crater is focussed. A plot of the colour temperature of the comparison lamp against screen illumination gives a curve showing a well defined maximum of illumination (fig. 15) from which the colour of the light when the crater is in focus can be easily determined.

The Isolated Basins Electricity Scheme, Upper Egypt.

By CLIFFORD S. ICKRINGILL, G.E.C. Resident Engineer, Egypt,
and H. PETERS, B.Sc., A.M.I.Mech.E., Overhead Transmission Dept. of The General Electric Co., Ltd.

IT is not always appreciated that while Egypt consists largely of a vast expanse of barren desert, there is a population of 15 million people who are more or less dependent upon the land for their livelihood, and as there is little tendency towards commercialisation, the intensive development of the comparatively small area of fertile land is of paramount importance. It should be remembered in this connection that, apart from the Nile, Egypt is practically devoid of water supply, and since the rainfall is almost negligible other means have had to be introduced to irrigate the land so that the ever-increasing population can be supported.

The Nile Delta provides part of Egypt with a complete system of natural canals and it is thus possible in the Delta area to irrigate at any time of the year, permitting the growth of two or three crops per annum compared with the single crop which it is only possible to grow in the Nile valley where artificial irrigation has not hitherto been developed to any extent.

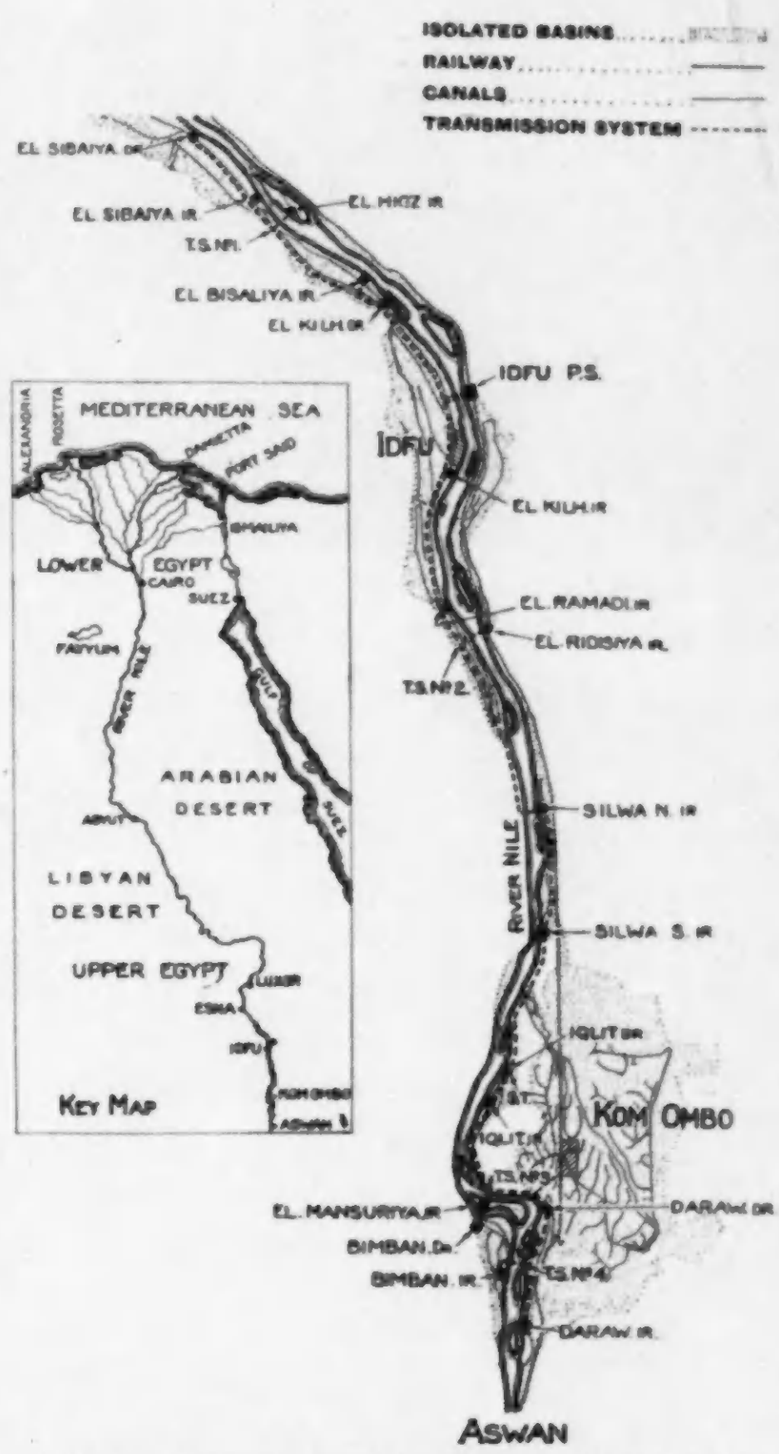


Fig. 1.—Upper Egypt showing Isolated Basins situated along the banks of the Nile.

South of the Delta the Nile flows in a single bed through barren desert. Along the banks, however, are situated a number of fertile areas separated from one another by desert patches extending right to the river's edge. For this reason these fertile areas are known as the "Isolated Basins." They occur at fairly frequent intervals in Upper Egypt which stretches from Wadi-Haifa to the South of Cairo (fig. 1).

The level of the Nile is low for three months every year from February to April. It begins to rise at the beginning of May, rising approximately 20 feet. By August, all the Isolated Basins are flooded, and high Nile continues during September and October. The water then subsides gradually into its normal bed leaving the land sufficiently moist for one crop to be raised. Apart from this annual flooding the only irrigation available is by means of primitive native water elevators called "Sakyas." These consist of an endless rope belt to which are secured a number of earthenware pots which dip into the water at the bottom of the well and discharge at the top into a channel whence the water is led away to the fields. They are driven by a horizontal wooden shaft and wooden gear wheels, the power being supplied by blindfolded oxen which go round and round in a circle from morning till night.

In addition to the "Sakyas," the "Tambour" is used to spread the water over the land, and is a very primitive contrivance which, worked by hand, draws water out of the channels over the land. In fig. 2 are shown a group of natives operating a "Tambour."

In consequence of the shortage of water it is necessary to confine irrigation at any one time to small areas of land, and figs. 3 and 4 show how the land is divided up. Fig. 4 is of particular interest in that it illustrates the sharp dividing line between the irrigated land and the desert, the latter being visible in the immediate foreground.

The population of Upper Egypt has gradually increased until the available fertile areas, although as intensively cultivated as possible, have become barely sufficient to support it. The Egyptian Government, therefore, decided upon an electri-

fication scheme which would enable the land to be irrigated and drained in a modern and adequate manner. This scheme consists of a number of electrically driven pumping stations which are

Fig. 2.—Fellaheen operating a "Tambour," a primitive water pumping device.

supplied with power from a generating station at Idfu by means of high tension overhead transmission lines. The Aswan Dam is at present being heightened and as a result it will be possible to retain the flood water behind the dam and keep the river within its bank. By opening and closing the sluices as required, the river will be kept at a more or less constant level throughout the year. The land will be irrigated by means of the pumping stations which will drive the water through the canals cut between the fields. The fertility of the existing cultivated areas will be considerably improved as not only will it be possible to raise three crops annually but further large areas which are at present barren desert will be rendered fertile.

DETAILS OF THE SCHEME.

Idfu was chosen as the distributing centre of the scheme on account of the railway facilities on the one hand and the convenient site on the east bank of the Nile on the other. The station itself is shown in fig. 5, while the width of the Nile at this point can be seen in fig. 6.

The power station contains two turbo-alternator sets running at 3,000 r.p.m. each having a rated output of 2500 kVA with an overload capacity of 25 per cent. Power is generated at 3,300 volts, 50 cycles, 3 phase. At present the supply is stepped up to 33,000 volts and transmitted overhead to the pumping stations. All the transformers together with the overhead lines have, however, been supplied suitable for operation at 66,000 volts at a later date. The complete scheme includes seventeen pumping stations, twelve for irrigation purposes and five for drainage. Of the five drainage stations only three have at present been built, the stations at El Sibaiya and Bimban being in abeyance. The contract for the

Fig. 3.—Cultivated land in one of the Isolated Basins.

supply and erection of the necessary overhead transmission lines, together with four transforming stations, one switch station and four 3,300 volt submarine cable crossings of the River Nile was awarded to the G.E.C. by the Egyptian Government.

Starting at Idfu power station, which is situated on the East Bank of the Nile, the overhead transmission system crosses the river, the two three-

Fig. 4.—Illustrating the sharp dividing line between the cultivated land and the desert, part of which is seen in the foreground.

phase single circuits being carried on two special high crossing towers (fig. 5). On the west bank of the river the two circuits divide. One runs approximately northwards feeding on the way (by means of branch lines) the following pumping stations :—

1. El Kilh (Drainage).
2. El Bisaliya (Irrigation).
3. El Higz (Irrigation).
4. El Sibaiya (Irrigation).
5. El Sibaiya (Drainage).

The station at El Higz is situated on an island in the river and is fed by means of a 3,300 volt sub-marine cable which is connected to Transformer Station T.S. No. 1. The line terminates at El Sibaiya but the pumping station here is at present in abeyance and will be built at a later date.

The other circuit turns south from the Idfu river crossing and, running along the west bank of the river, feeds the following pumping stations :—

1. El Kilh (Irrigation).
2. El Ramadi (Irrigation).
3. El Ridisiya (Irrigation).

El Ridisiya is fed by means of a 3,300 volt sub-marine cable which is connected to Transformer Station T.S. No. 2. The line continues south until it reaches the village of Nag El Noash opposite Silwa N. where it recrosses the Nile and continues on the east bank feeding the following pumping stations :—

4. Silwa N. (Irrigation).
5. Silwa S. (Irrigation).
6. Iqlit (Drainage)—Switch Station.
7. Iqlit (Irrigation).
8. Daraw (Drainage).
9. Daraw (Irrigation).

In addition the following stations on the opposite bank of the river and on an island are fed by means of 3,300 volt submarine cables.

Fig. 5.—Atwania Power Station at Idfu, showing the two towers carrying the power cables across the Nile.

10. El Mansuriya (Irrigation) from Transformer Station T.S. No. 3.
11. Bimban (Irrigation) from Transformer Station T.S. No. 4.
12. Bimban (Drainage)—in abeyance.

LABOUR.

In describing the various installations it will be interesting to bear in mind that for the labour involved in transport to site and erection, the engineers in charge were dependent on the natives, or Fellaheen. These men are of the land and their knowledge of mechanics and electricity is nil. It will be appreciated, therefore, that the problems in regard to transport and erection had to receive careful planning in advance.

Fig. 6.—The Nile at Idfu where the power station is situated.

A total of about 14 engineers and foremen was engaged in the execution of the work and at the peak of the work a total of approximately 400 natives was employed. The temperature in Upper Egypt during the hottest months of the year is very high and on occasion reaches 132°F in the shade.

So far as transport was concerned the Nile itself was a great asset since it was possible to bring the equipments from Alexandria to within 5 miles of their final destinations, and in this manner the transport of well over 1,000 tons of material was accomplished.

One of the most difficult problems was the transport of the transformers, some of which weighed 7½ tons gross, from the Nile bank to site. In some cases the site is a considerable distance from the Nile and it is interesting that only six short lengths of Decauville tracks were used for the longest cross-desert journey. Figs. 7, 8, 9, 10 and 11 show respectively the arrival of two transformers at the Nile bank, the first steps towards unloading them, two views during transport and their arrival on site.

OVERHEAD TRANSMISSION LINES.

The total length of the overhead transmission lines is approximately 115 kilometres.

The line conductors are stranded hard drawn copper composed of 19/1.83 mm. strands having a

cross-sectional area of 50 square mms. with an overall diameter of 9.15 mms. The maximum working tension (based on a factor of safety of 2) is 800 kilograms. There are three line conductors forming one three-phase single circuit and an over-running galvanised steel earth conductor, composed of 7/2.53 mm. wires having a cross-sectional area of 35 square mms. with an overall diameter of 7.59 mms.

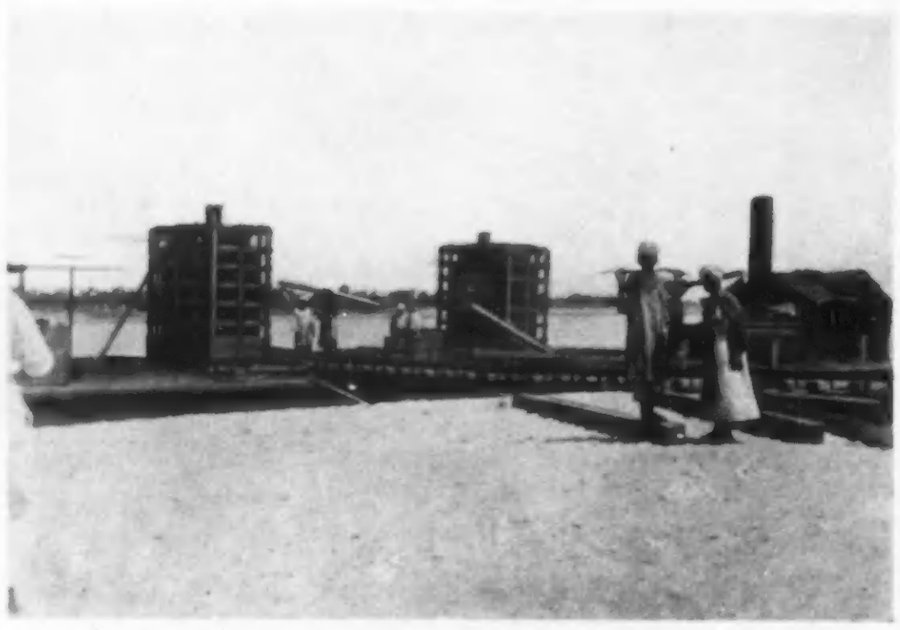


Fig. 7.—Two of the transformers arriving by barge at Nile Bank.

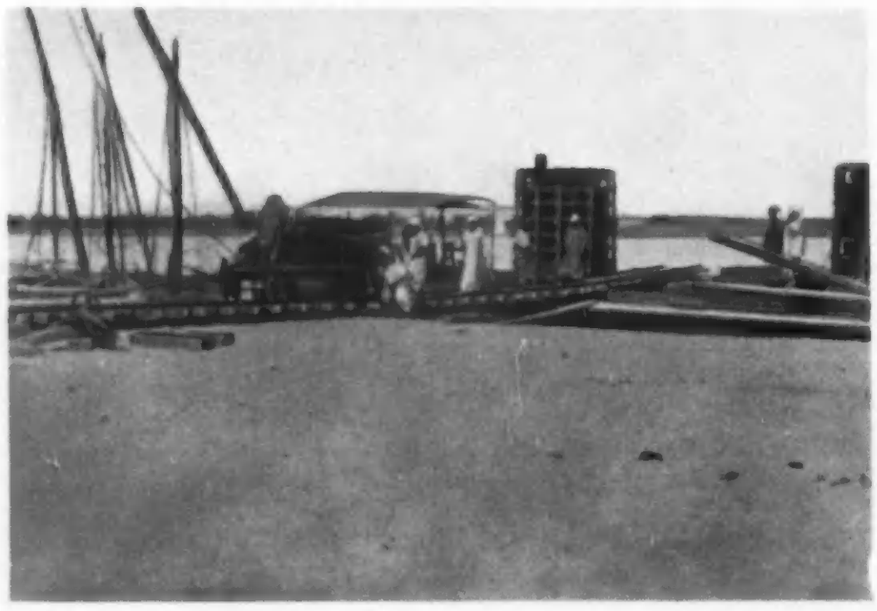


Fig. 8.—Starting to unload the transformers.

The lines are insulated for a working pressure of 66,000 volts by means of single four-unit suspension strings on suspension towers, and double five-unit tension strings on angle and strain towers. The insulator discs have a diameter of 25.4 cms. and are of the spring ring cap and pin type, the special feature of which is that the insulator pin is fixed mechanically instead of by cement. A spiral spring ring of high tensile steel wire carried on the stem of the pin is forced through the neck of the hollow cylindrical space in the head of the insulator and allowed to expand into the wider cavity, the shape of which is designed to conform in curvature with that of the spring itself. The spring is retained in position by means of a second spring and clip, the space between being filled with a lead alloy to protect the spring, prevent relative movement and secure a better distribution of the electrical and mechanical stresses. The tension on the pins is thus converted into uniform compression over the whole of the inside of the insulator. The units are connected together by means of a ball and socket.

A power arc protective device in the form of a "W" type arcing horn fitted at each end of the insulator strings is used on the towers on the branch lines only, *i.e.*, between the junction towers on the main lines and the pumping or transformer stations. The line and earth conductors are carried in suspension clamps on suspension towers, while cone tension clamps are used on angle and strain towers. The line and earth conductor tension joints are also of the cone type. The line towers are of the self supporting lattice steel bolted type. The top portion is galvanised, while the bottom portion (from approximately 2 metres below the bottom crossarm) is painted. The towers are of the following types :—

1. Suspension S_1—straight line and angles up to 5°,
2. Suspension S_2—angles between 5° and 15° and road and rail crossings.
3. Anchor towers—one every 5 kilometres approximately.
4. Angle towers—angles between 30° and 60°.
5. Terminal towers—at ends of main and branch lines.
6. Special towers—such as junction and transposition towers.

The route of the lines has been so laid out that angles of deviation between 15° and 30° are avoided.

The towers have concrete foundations, a separate concrete block extending 40 cms above ground level being provided for each of the four legs. The

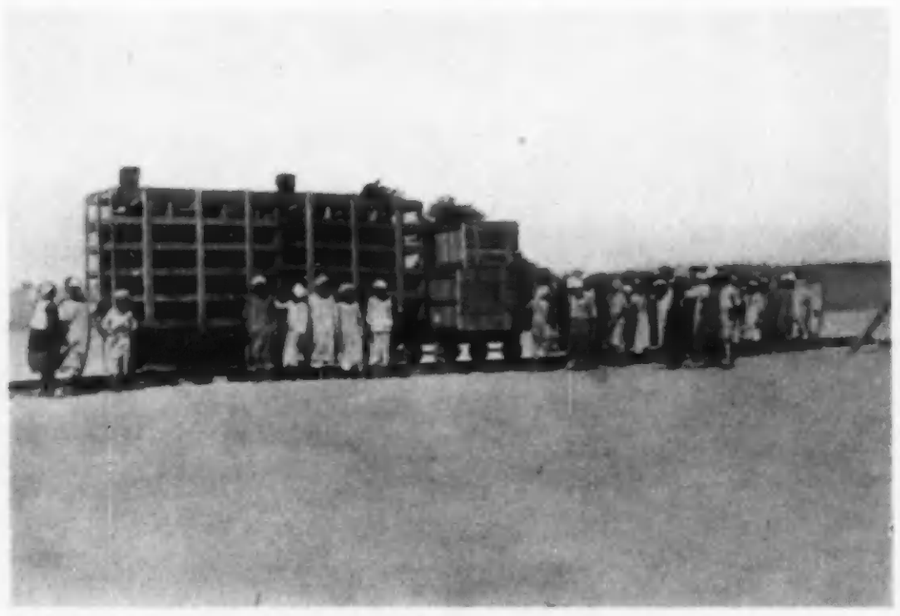


Fig. 9.—Transformers en route across the desert.

soil is mainly clay or loam and stony in places, but in the hilly districts rock, limestone and sandstone are encountered. The maximum earth pressure allowed is 1 kilogram per square centimetre.

The towers have been designed to carry the line and earth conductors, insulators and all fittings, the vertical, longitudinal, and transverse loads

imposed by the conductors together with a wind pressure of 40 kilograms per square metre on the whole projected area of the line and earth conductors and a wind pressure of 125 kilograms per square metre on 1½ times the projected area of the members in one face of the tower. No allowances had to be made for extra loads created by snow or ice as neither of these occur and rain is very rare. Under the above simultaneous working loads the towers have a factor of safety of 2½ on the elastic limit of the steel. In addition, the towers will withstand the simultaneous working loads modified by the following broken conductor conditions with a factor of safety of 1½ on the elastic limit.

Suspension S_1—any one line or earth conductor.
Suspension S_2—any one line or earth conductor.
Anchor towers—any or all of the line and earth conductors on either side.
Angle towers—any one line conductor simultaneously with the earth conductor.
Terminal towers—any combination of line and earth conductors.
Special towers—any or all of the line conductors on either side.

The conductors are erected having a sag in still air such that at a temperature of 0°C with the specified maximum loading conditions, the factor of safety is not less than 2 based on the ultimate strength of the conductor. The minimum clearance between the line conductors and the ground in still air with a maximum sun temperature of 90°C is 6 metres, while the minimum clearance at railway and road crossings is 8 metres, and at crossings of other power lines 3½ metres. A minimum clearance of 4 metres is provided over buildings, etc. Duplicate

Fig. 10.—Method employed of moving transformers.

insulator strings are used at all road, rail and canal crossings. The normal span is 200 metres and the average overall height of the towers is 15½ metres. The suspension towers are 2 metres square overall at the ground level while the other types are 3.3 metres square. A complete rotation of the line conductors is effected approximately every 20 kilometres by means of transposition towers. Each tower is earthed individually by means of a cast-iron earth pipe buried vertically in finely broken coke and connected to the tower steelwork by copper bonds.

OVERHEAD RIVER CROSSINGS.

The overhead transmission lines cross the River Nile at Idfu and at Silwa N.

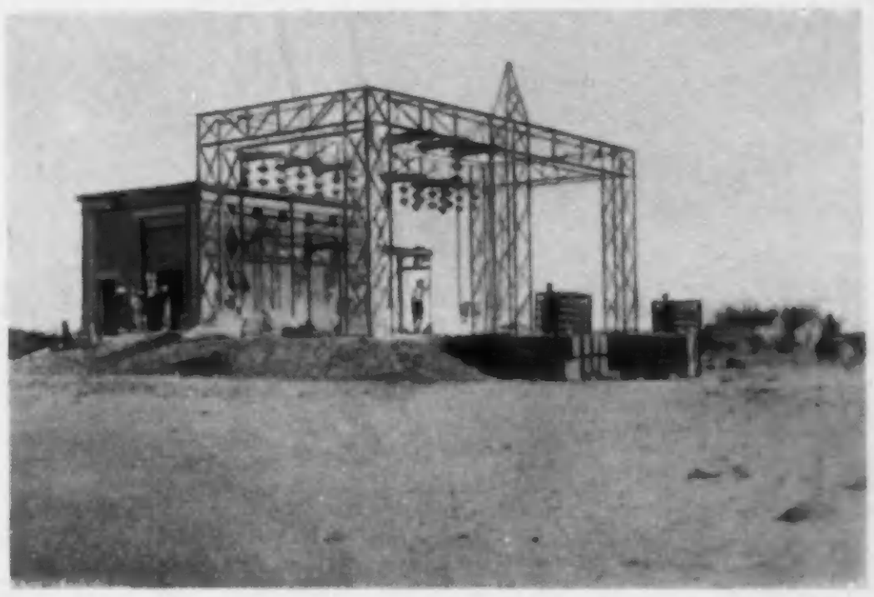


Fig. 11.—Arrival of transformers on site.

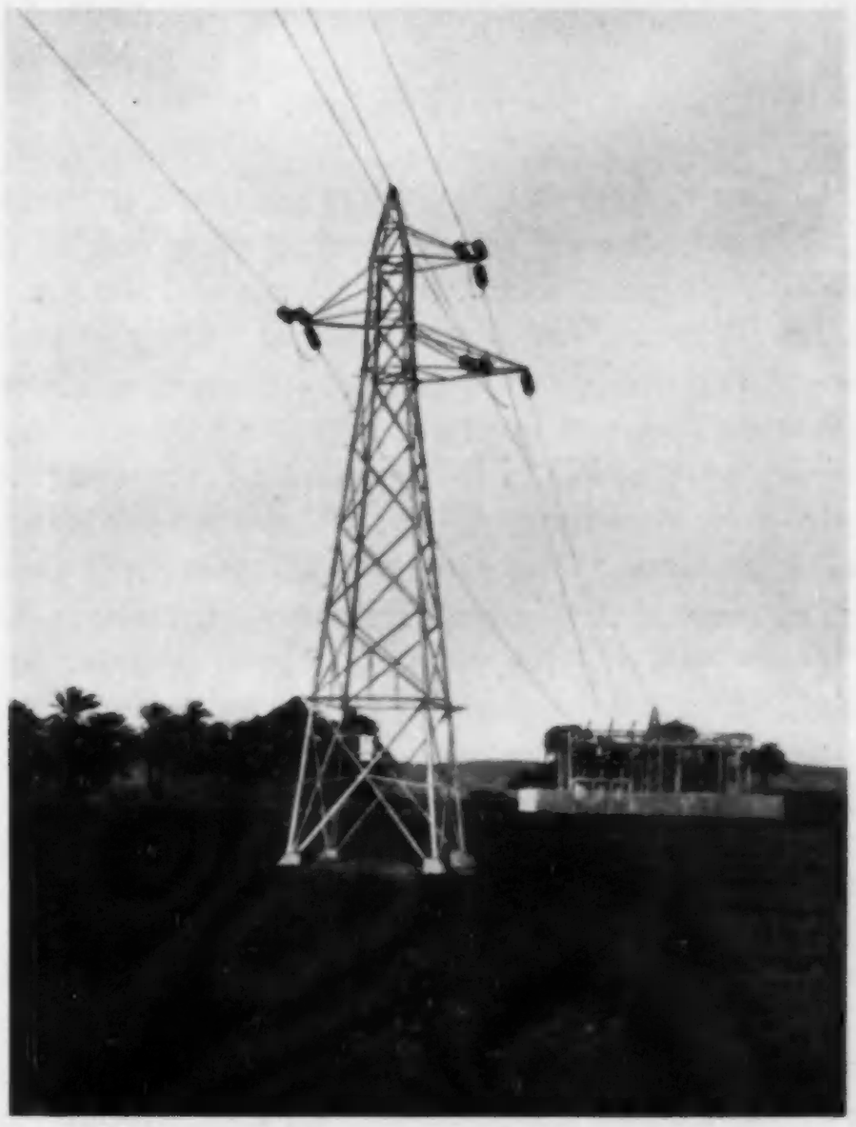


Fig. 12.—Branch line terminal tower with El Higz Transforming Station in distance.

At Idfu the two circuits are carried on two 93 metre lattice steel terminal type crossing towers which can be seen in fig. 5. Special stranded cadmium copper conductors are used in the crossing span only, composed of 19/2.1 mm. strands having an equivalent copper area of 70 square mms. with an overall diameter of 10.5 mms. In addition to the six

line conductors there is a common overrunning galvanised steel earth conductor. Special high strength tension insulator sets are used on the crossing towers and comprise two strings of seven units in parallel. The insulator units are of the spring ring type, 28 cms. in diameter, and the complete sets have an ultimate tensile strength of 10,000 kilograms, the maximum working load being 3,400 kilograms. Protection against power arcs is provided by means of "W" type arcing horns fitted at each end of the insulator strings. The crossing span at Idfu (fig. 5) is 690 metres. The overall height of the crossing towers is approximately 93 metres giving a minimum clearance of 45 metres above high water.

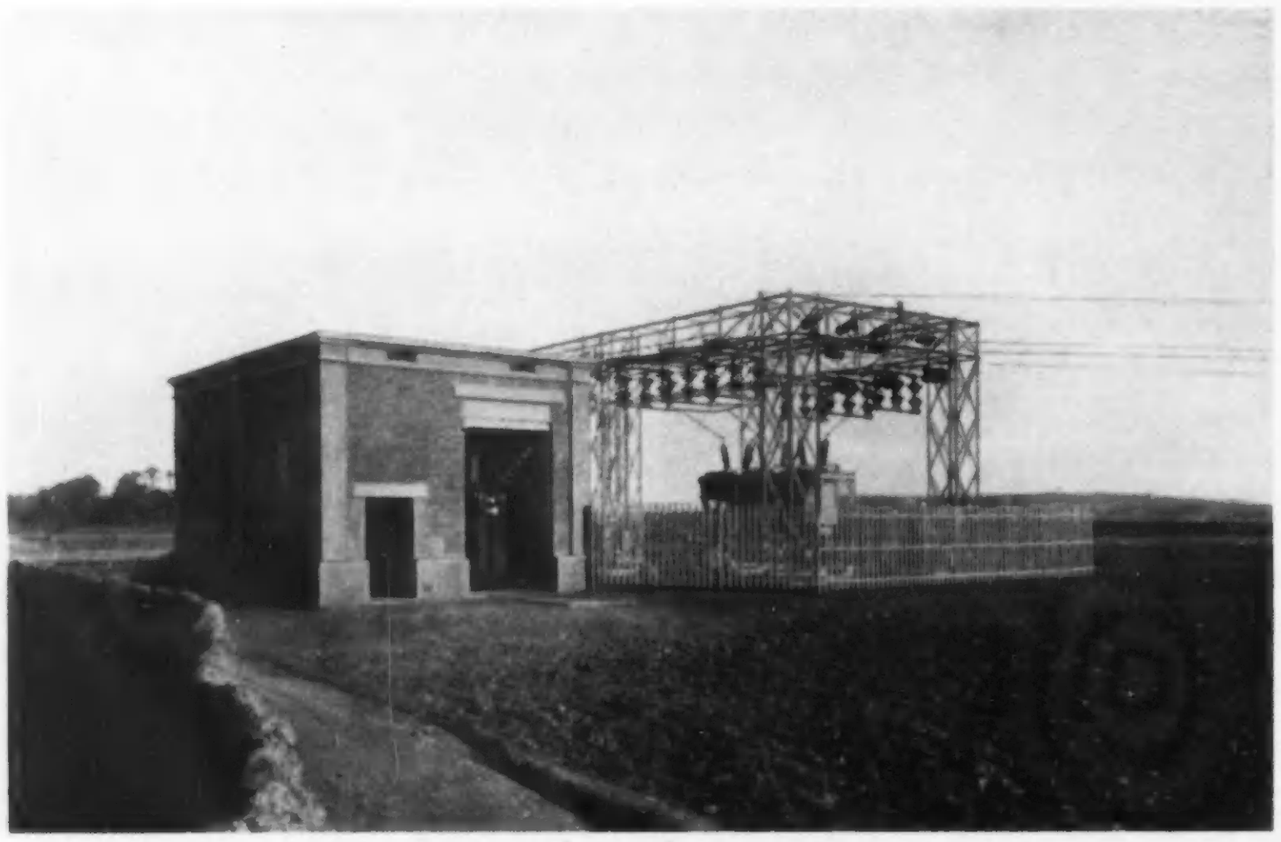


Fig. 13.—El Higz Transforming Station.

The southern single circuit line recrosses the River Nile opposite Silwa N. pumping station. The crossing span is 720 metres, the towers being of the terminal type approximately 91 metres overall in height giving a clearance of 45 metres above high water. As in the case of the Idfu crossing, cadmium copper line conductors are used together with double string tension insulator sets. In addition to the three line conductors there is an over-running galvanised steel earth conductor.

TRANSFORMING STATIONS.

The load on the transmission lines consists of static transformers mainly feeding induction motors direct. Where the pumping stations are on the route of the transmission lines the transformers and switchgear were supplied with the pumping plant. Two of the stations, however, are situated on the opposite bank of the river and two are on islands in the river. These four pumping stations are fed by means of 3,300 volt submarine cables from four transforming stations marked T.S. No. 1, 2, 3 & 4 in fig. 1, and illustrated in figs. 13, 17, 19 and 21. Each transforming station consists of an outdoor galvanised lattice steel structure carrying the H.T. switchgear and circuit breakers and a transformer house containing the power transformers, low tension switchgear, lighting transformers, etc.

All four transforming stations are alike except as regards the capacity of the transformers. Three of them each contain two 535 kVA, 3-phase transformers, 66,000/33,000/3,300 volts, 50 cycles, the fourth station housing two similar 212 kVA transformers.

Fig. 14 shows the connections at each of the transforming stations. The incoming lines are connected to H.T. busbars on the outdoor switch structure through a 66 kV gang-operated triple pole rotary air break isolating switch having a capacity of 300 amperes, and a 66 kV 1,500,000 kVA, three-phase outdoor type oil circuit breaker complete with control gear. There are, in addition, two 300

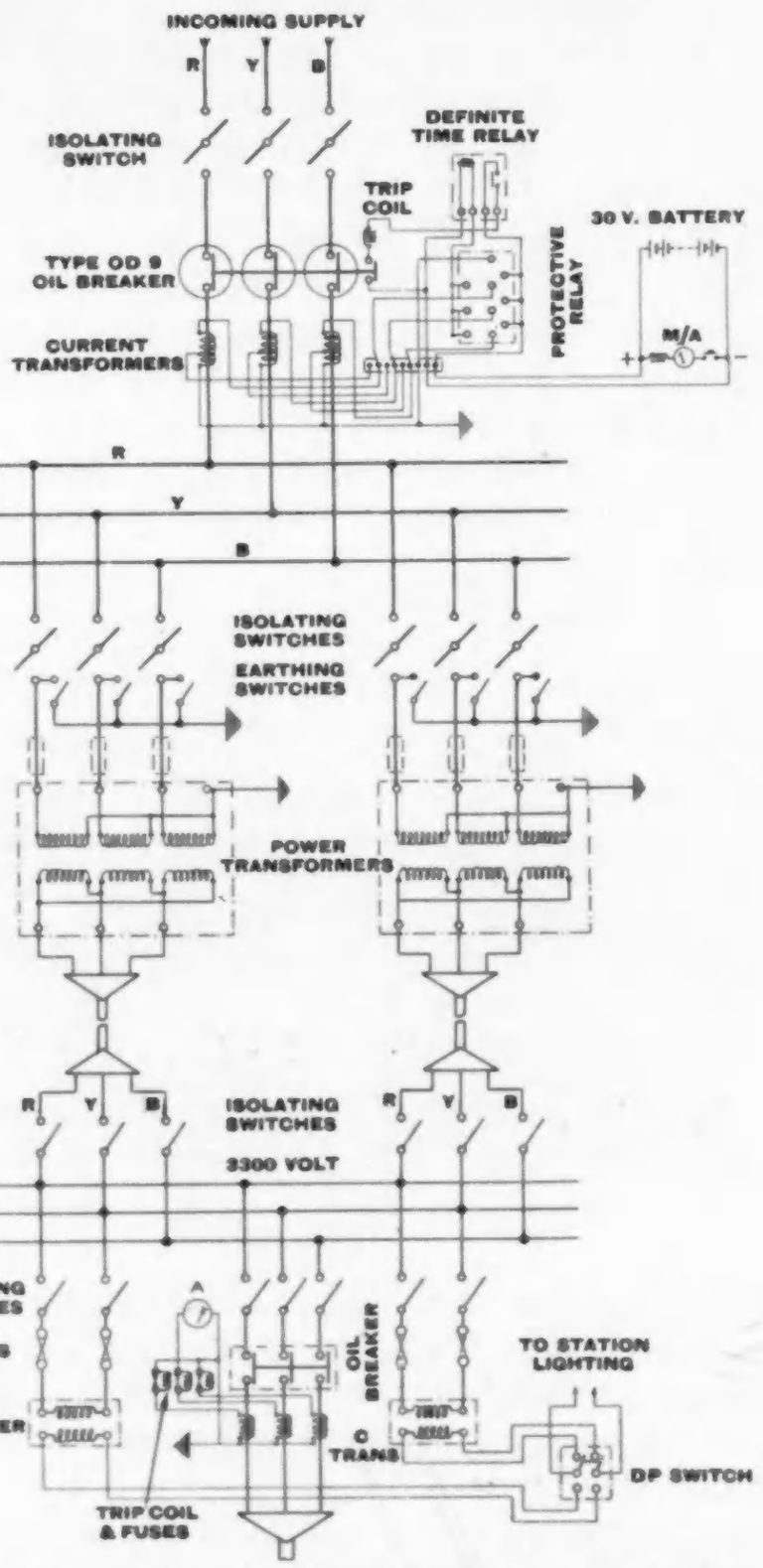


Fig. 14.—Diagram of connections at transforming stations.

ampere gang-operated triple pole rotary air break isolating switches with earthing links, which connect the two power transformers to the H.T. busbars.

Each transformer house also contains two lighting transformers and the necessary low tension switch-gear mounted in three totally enclosed non-interlocked steel plate cubicles.

66 *kV Air Break Isolating Switches* — The air break isolating switches (fig. 16) are designed for operation whilst the circuits are alive with no current passing. The design ensures that the three phases are opened or closed simultaneously by means of levers operated from the ground level. The operating mechanism embodies locking arrangements in the "on" and "off" position and these ensure that the switches cannot be opened by forces due to surge currents.

The interlocking system between the isolating switches and the co-related circuit breakers is extremely efficient and simple in operation. It includes "Castell" figure locks which are incorporated on the operating mechanism of the oil circuit breakers, isolating switches and earth switches. Each numbered lock can be operated only by the key bearing the number relating to that lock. For each station one key only is provided bearing any single number. A master key is however kept at the Idfu power station.

Fig. 15 gives details of the interlocking arrangements, a single line diagram for a complete three phase circuit being shown. Before these keys can operate, two conditions have to be satisfied. Condition No. 1 is that the oil circuit breaker must be open before the isolating switches can be operated. Condition No. 2 is that the transformer isolating switches must be open before the co-related earthing switches can be operated. The oil circuit breaker is normally locked in the open position. To close the breaker, key No. 1 is inserted and unlocked. This enables the breaker to be operated but at the same time the key is trapped in the lock and it is therefore not available for unlocking the isolators. Key 2 or 3 (according to which transformer is in use), is inserted in the outgoing co-related isolating switch and unlocked. This allows the isolating links to be closed but at the same time the key is trapped in the lock. This makes it impossible to unlock the co-related earthing switch.

Fig. 16.—66 kV rotating isolating links, lightning arresters and choke coils at El Higz Transforming Station.

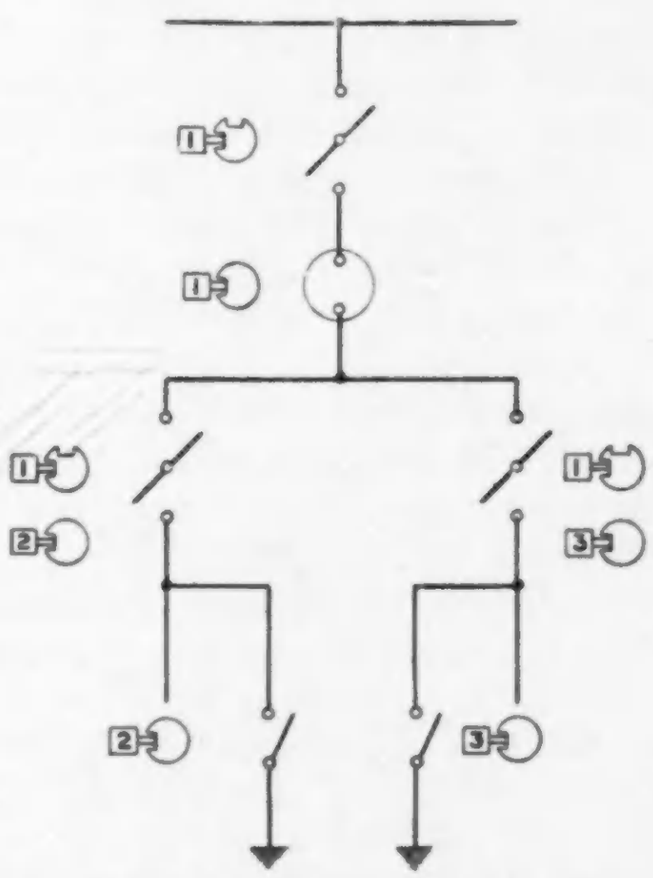


Fig. 15.—Schematic diagram of locks at transforming stations.

66 *kV Oil Circuit Breakers.* The oil circuit breakers have a rupturing capacity of 1,500,000 kVA and are capable of interrupting a fault of this value twice in rapid succession without damage. They comprise three self-contained single phase units in welded steel cylindrical tanks mounted on a steel framework of sufficient height to allow the tanks to be lowered for inspection of the contacts and mechanism. A complete single phase unit can be removed if necessary without dismantling the entire framework or disturbing the adjacent units.

The circuit breakers are designed for direct manual operation from the ground level. The operating mechanism embodies the free handle principle throughout the whole travel and it is not possible for the breaker to make contact whilst the protective relay contacts are closed. A powerful toggle system comes into action during the actual closing of the contacts and compression of the break accelerating springs. This reduces the force necessary for closing and also relieves the tripping gear of the bulk of the pressure in opening.

The impetus of the moving system is arrested at the end of the opening stroke by oil cylinder shock absorbers.

Each three phase circuit breaker incorporates a D.C. shunt trip coil energised from a 30 volt D.C. storage battery. The tripping circuit is broken on auxiliary contacts fitted to the operating mechanism and is not ruptured on the overload relay contacts. Each circuit breaker is complete with a three pole overload relay of the supersensitive induction pattern having definite time settings to facilitate grading, the settings being adjustable between 1 to 5 secs. The overload current settings are adjustable between normal full load and 300 per cent full load. The relay coils are energised from the secondary windings of the current transformers installed in each phase.

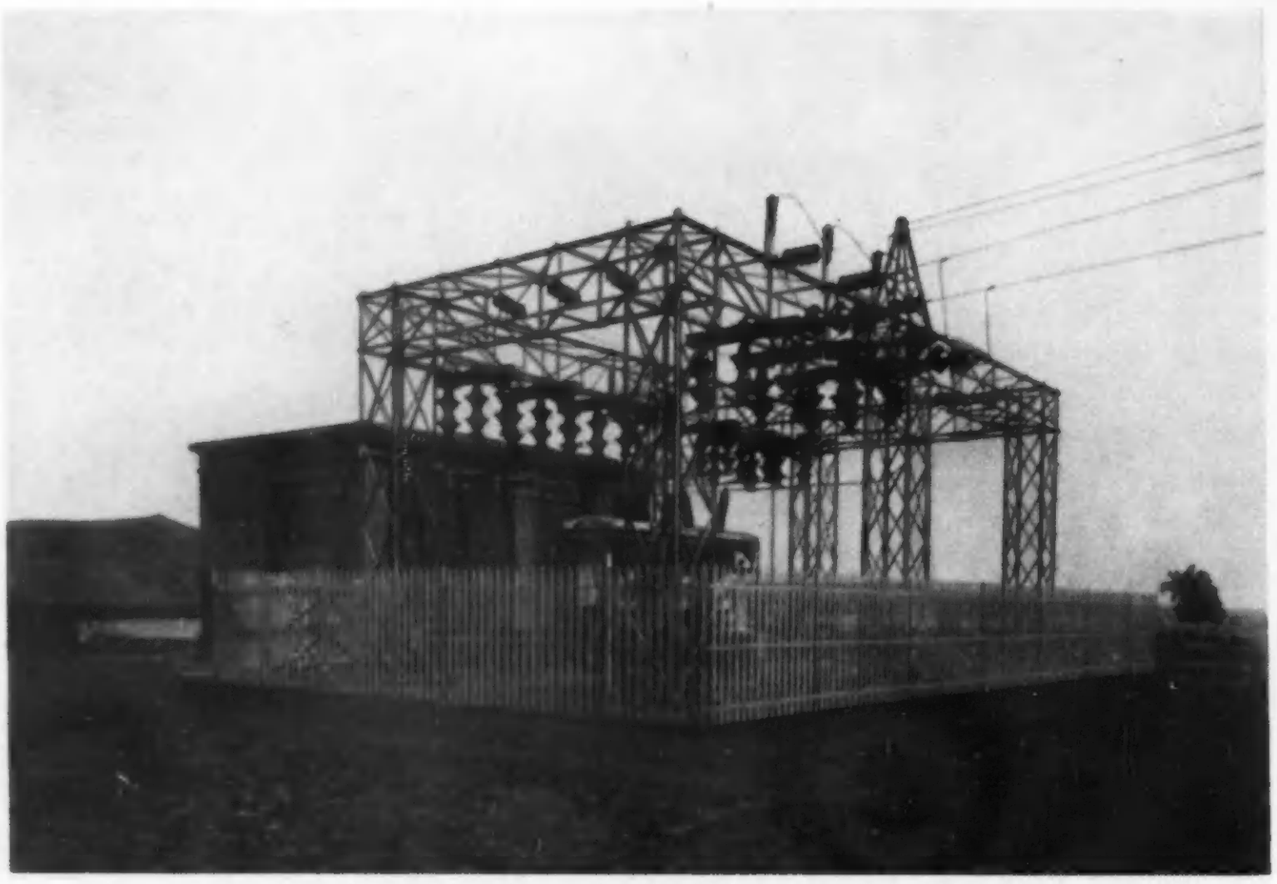


Fig. 17.—Transforming Station at El Ridisiya.

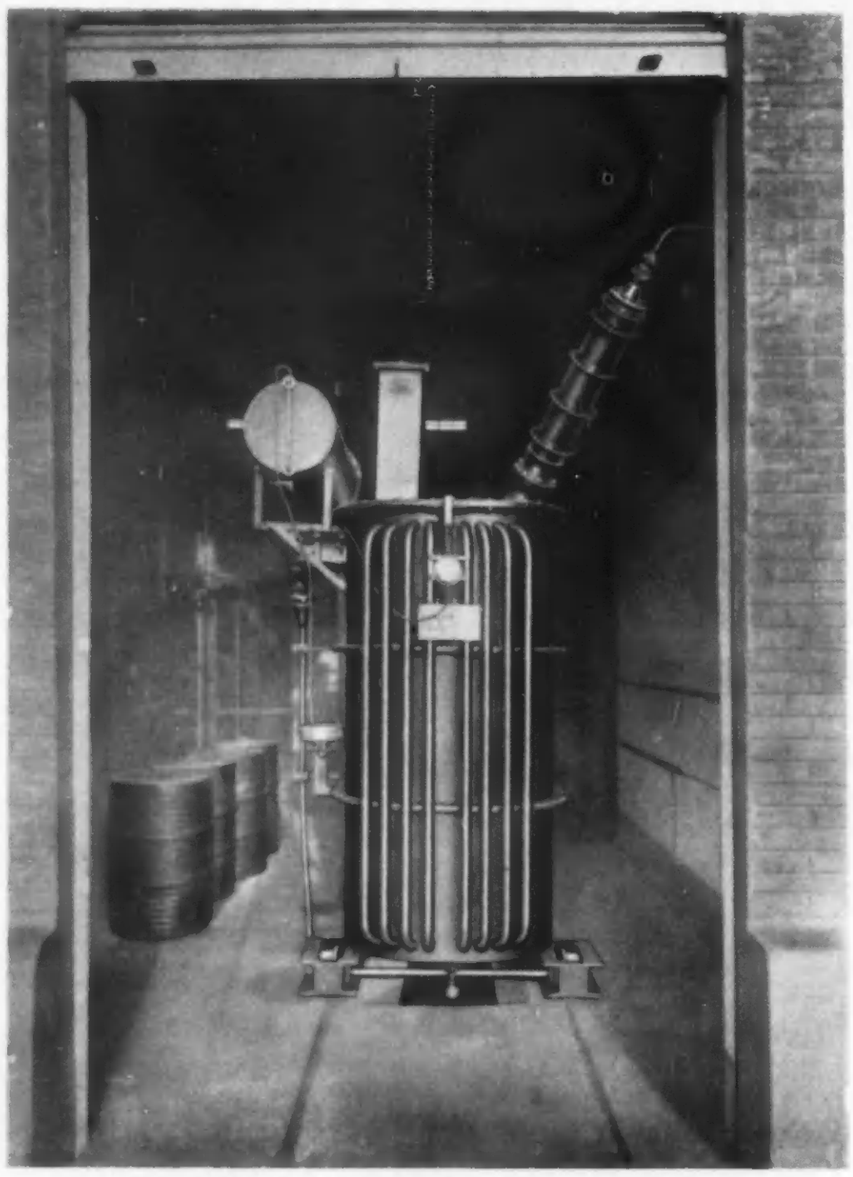


Fig. 18.—66/33/3.3 kV 3 phase transformer in transformer house at El Ridisiya.

Power Transformers. The three phase power transformers (fig. 18) are of the indoor, oil immersed, natural cooling, core type in steel tanks, and are capable of withstanding a pressure 30 per cent in excess of the normal rated pressure for 5 minutes on open circuit. They have their higher voltage windings star connected ,and their lower voltage windings delta connected, the neutral points of the higher voltage windings being connected to earth.

Since the initial transmission pressure is 33,000 volts and this will be subsequently raised to 66,000 volts the windings of the transformers have been designed for series—parallel connection. The windings have at first been connected in parallel for operation at 33,000/3,300 volts. By rearranging the windings in series, the transformers can be operated at 66,000/3,300 volts. Each transformer is fitted with two tappings which will allow the normal voltage on the secondary side to increase 5 per cent and 10 per cent without any reduction of the rated output. These tappings are operated by an "off" load tapping switch which enables the tapping to be altered without interfering with the oil level as would otherwise be necessary owing to the provision of oil conservators.

The transformer cores are of standard G.E.C. 3-phase construction. All joints are of the interleaved type. The H.T. windings are of the cross-over type and the L.T. windings of the multi-layer type. Each transformer is provided with standard calcium chloride breathers.

As a continuous earth wire is provided on the transmission lines no special protective gear against

transient atmospheric disturbances is installed at the transforming stations.

Low Tension Switchgear. A low tension cubicle type switchboard comprising three totally enclosed non-interlocked steel plate cubicles complete with busbars, inter-connections, etc., is installed in each transformer house, the equipment in detail being as follows :—

Two side cubicles each fitted with :
Three 200 amp. single pole knife isolating switches, connected to the secondary side of the power transformers.
One trifurcating box suitable for 3 core cable.
Two single pole knife type isolating switches for the Lighting transformers.
Two single pole H.T. fuses for the Lighting Transformers.
One 1 kVA single phase 50 cycles 3,300/220/110 volt Lighting transformers.

Centre cubicle containing :—
One 200 amp. 25,000 kVA triple pole loose handle oil circuit breaker having three overload trip coils.
Three time limit fuses.
One 6 inch dial moving iron ammeter.
Three air cooled current transformers.
Three 200 amp single pole knife type isolating switches.

The low tension oil circuit breakers are of the manually operated type, the handle projecting through the front plate of the cubicle. The single pole knife switches are arranged for pull rod operation.

The two lighting transformers supply the necessary station lighting, one of the two being used as a spare. Each station is in addition equipped with a 30 volt storage battery for operating the D.C. shunt trip coils on the 66 kV oil circuit breakers.

SWITCH STATION.

In addition to the four transforming stations already described, an outdoor line sectionalizing switch station is provided at Iqlit on the southern transmission line. This switch station consists of an outdoor galvanised lattice steel structure, as installed at the transforming stations, arranged for receiving the "in" and "out" line conductors. The connections at the switch station are shown in fig. 20. Two 66 kV gang operated triple pole rotary air break isolating switches are provided, one with earthing links and one without, together with a 66 kV three phase outdoor type oil circuit breaker complete with control gear. This switchgear is in all respects similar to that installed at the transforming stations. The "Castell" interlocking arrangements are similar to those already described and ensure that the oil circuit breaker must be open before the main line isolators can be operated, also that the outgoing main line isolators must be open before the earthing switch can be closed.

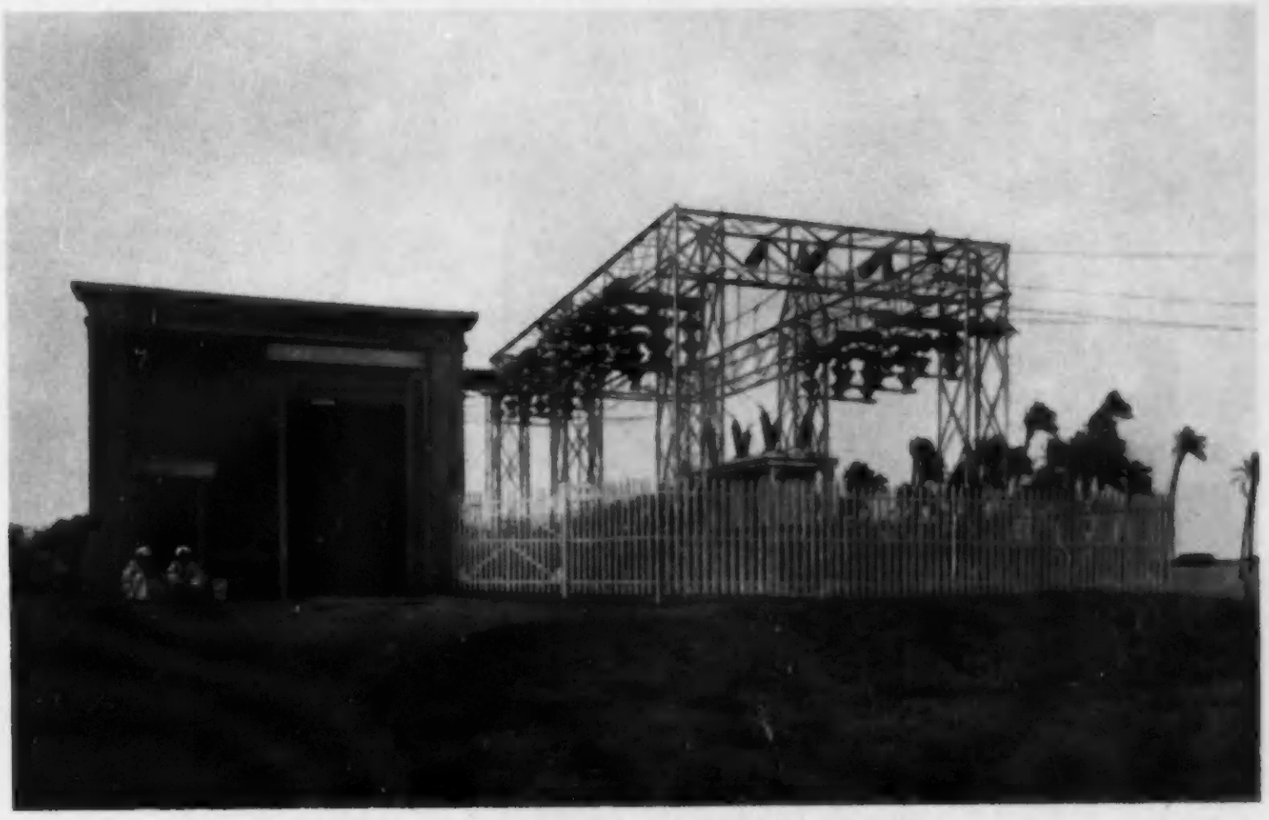


Fig. 19.—Bimban Transforming Station.

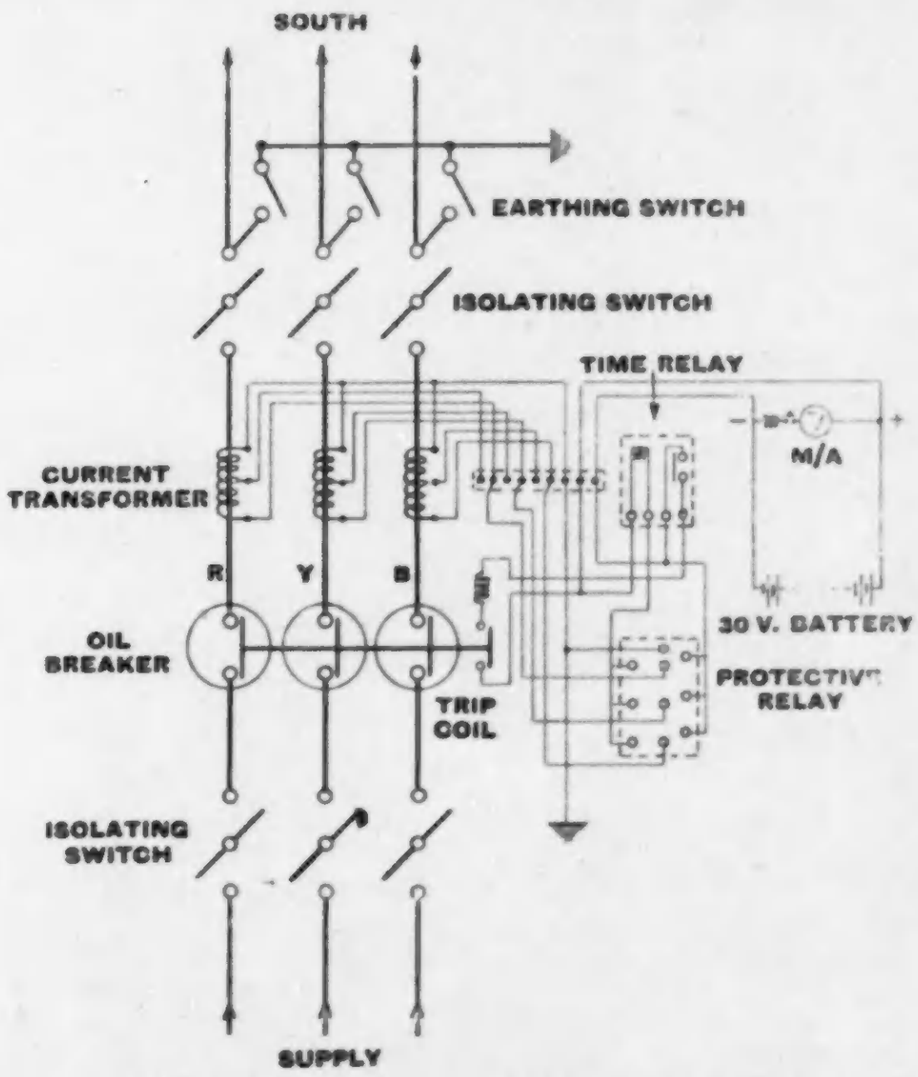


Fig. 20.—Diagram of connections at switch station.

SUBMARINE CABLES.

The 3,300 volt submarine cables are of the three core paper insulated, lead sheathed, double steel wire armoured type. In the case of transforming stations T.S. No. 2, 3 and 4 the cores are

composed of 19 annealed copper wires having a total cross sectional area of 65 square millimetres giving a current carrying capacity of 300 amperes. The cable connected to transforming station T.S. No. 1 has an area of 25 square millimetres, each core containing 7 wires and having a current carrying capacity of 160 amperes. Each cable is laid in one length between anchors.

ERECTION AND TESTING.

The erection on site of the overhead line towers and conductors was carried out by Brown Boveri on behalf of the G.E.C.

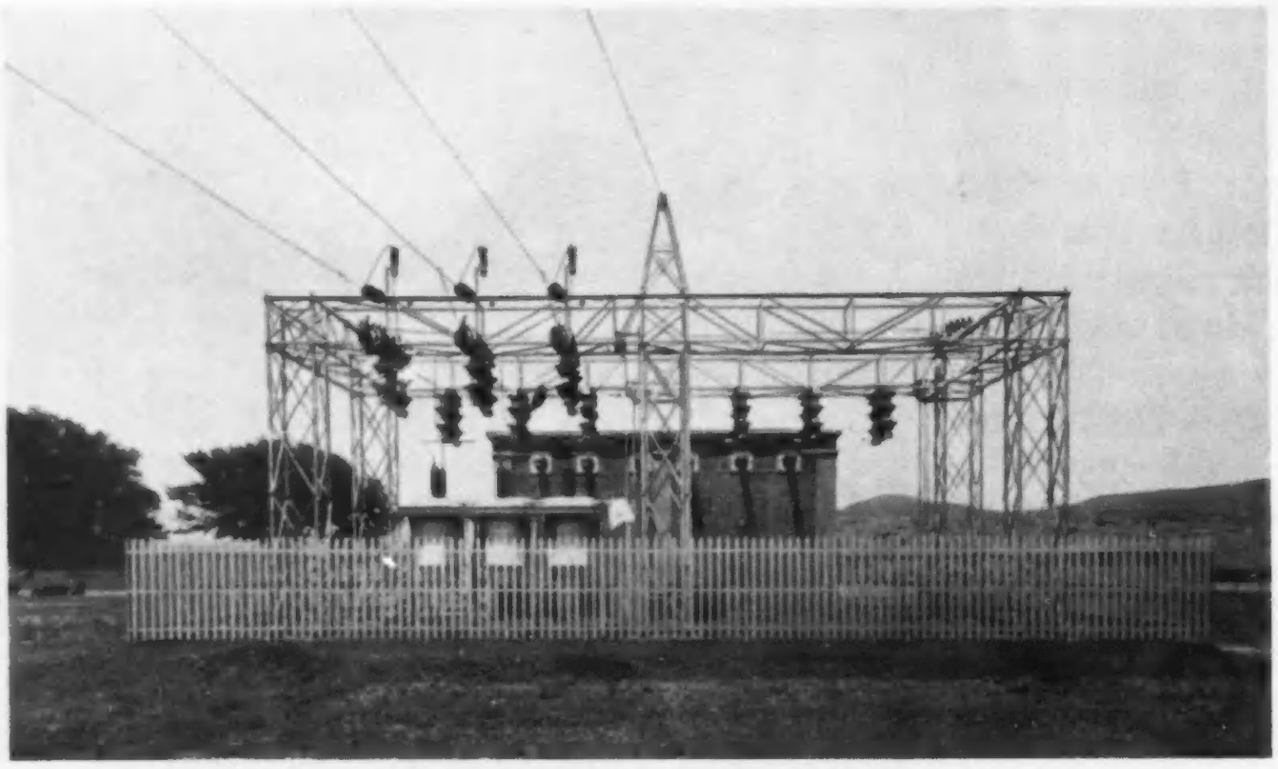


Fig. 21.—Another view of El Ridisiya Transforming Station showing the oil circuit breaker under the rotary isolating links.

After erection, insulation and conductivity tests were carried out on the plant at 66,000 volts, while all the transmission lines were tested at a pressure of 90,000 volts.

Electric Locomotive for Cardiff Corporation

10-ton electric locomotive for Cardiff Corporation driven by two 50 h.p. motors, 500 volts, and capable of hauling a load of 120 tons at 6 miles per hour.

Sports Lighting.

By M. W. PEIRCE,
Illuminating Engineering Dept. of The General Electric Co., Ltd.

MOST of the time available to the average citizen for recreation unfortunately occurs during the hours of darkness. Indeed, the popularity of the Summer Time Act affords adequate proof of the need which exists for facilities for sport and recreation outside business hours.

In such communities as the Universities, the value of sport is rated so highly that it is a general rule that the afternoons should be set apart for this purpose, leaving the mornings and evenings for lectures and study. While this University system largely solves the problem of sports lighting by making it to a certain extent unnecessary, it is manifestly impossible for the business world to adjust itself to this procedure and the alternative is obviously the provision of adequate artificial illumination.

A considerable amount of progress has already been made in this direction and practicable lighting schemes can now be provided and are in existence to enable almost every kind of sport to be carried on after dark.

Sports lighting installations cater for the needs of two main classes of people:

1. Those who wish to play.
2. Those who wish to watch.

The value to a community of adequate facilities for actual play cannot be over-estimated. At the same time the needs of the spectators have to be considered, and large numbers would attend in this capacity at night, if suitable lighting were provided.

Fig 1.—Amwell swimming pool floodlighted at night.

On the one hand, sports which are able to attract a large public are naturally able to justify greater expenditure on the lighting installation. On the other hand, the lighting problems are greatly simplified if it is not desired to attract spectators, so that illumination schemes for players only are just as practicable financially.

GENERAL CONSIDERATIONS.

In general, it is necessary for sports lighting to provide high illumination intensities in order to give clear vision of the fast moving objects associated with most ball games. It may be mentioned here

that this immediately brings into prominence the question of glare. While it may be possible to light a room or area in a certain way with complete freedom from discomfort due to glare, it in no way

Fig. 2.—Collapsible lighting fitting used for dog tracks where the grounds are used by day for football, etc.

follows that the illumination values can be doubled or trebled by simply increasing the wattage of the units without the introduction of serious glare, sufficient to make play impossible.

The following fundamental considerations must be reviewed when any sports lighting problem is to be solved:

1. Provision of sufficient intensity both for players and spectators. It may be found that intensities must be increased when there are spectators.
2. In the case of ball games, even intensity not only near the ground but also in the air.
3. Absence of glare to spectators and players.
4. Protection of fittings from mechanical damage.
5. Avoidance (for the benefit of spectators) of obstacles to vision.
6. Spectacular effect.

It will be seen that of these considerations, only the first four apply if players alone are concerned, while items 5 and 6 may be expected to lead to considerable elaboration of a lighting scheme.

ESTIMATING INTENSITIES.

While the intensity required for a particular sport is arrived at in most cases by a combination of illumination experience and a system of trial and error, it may be of interest to mention an analytical method applicable to all illumination problems which was the subject of a paper read before the Illuminating Engineering Society.*

The system involves the assumption of a basic illumination of one footcandle for the simplest optical task of comprehending a large black shape on a perfectly white ground, and this figure is multiplied by a series of factors based upon such considerations as:

1. Contrast, *i.e.*, reflection factor differences between object and background.
2. Size of object (angle subtended at the eye).
3. Moving vision (relative movement between observer and object).
4. Emphasis factor, which is closely allied to "spectacular effect" mentioned above.

As an illustration of the application of this system, let it be assumed that it is required to estimate the correct intensity for greyhound racecourse illumination. The multiplying factors would be obtained as follows:

Fig. 3.—A daylight view of the same track shown in fig. 2, showing dog track lighting fittings mounted on collapsible poles.

Contrast. Assuming that the object to be comprehended is the coat used for indentification of the dog, having a reflection factor of, say, 0.6, and that the background will be grass green with a reflection factor of 0.18, the reflection factor difference is $0.6-0.18 = 0.43$, for which figure a factor of 2.5 would be used.

Size. The identification coat when viewed from across the track subtends at the eye an angle of 5

*—"The Illuminating Engineer." January, 1934.

to 10 minutes of arc and the multiplying factor recommended for this range is 1.5.

Moving Vision. The speed of the dog is in excess of 30 miles an hour and as spectators are accommodated close to the fences, the movement must be considered to come under the category of "fast," the appropriate multiplying factor being 3.

Emphasis. This is a matter which must depend on the situation of the track, *i.e.*, whether a spectacular effect is required to compete with nearby attractions. The multiplying factor may be unity if no emphasis is required, 1.5 for "close attention" and 2 if special emphasis is to be provided.

It will be seen that assuming a basic illumination of 1 footcandle and multiplying this figure by each of the factors arrived at above, the intensity which is necessary is 11.5 footcandles ($1 \times 2.5 \times 1.5 \times 3 \times 1$) while an increase to as much as 23 footcandles will occur if the factor 2 is used for special emphasis.

As has been said, suitable intensities have been arrived at for most sports before the above system, founded on basic principles, was put forward, and experience and experiment have shown that for dog track lighting a minimum intensity of 8 to 10 footcandles should be provided, though intensities in excess of 20 footcandles are common in popular areas. The multiplying factors can only be chosen arbitrarily until they have been checked against a very large number of installations, but it will be agreed that in this case the results obtained are surprisingly accurate.

It will be noted that in the analytical calculation the nature of the lighting is not considered and the results therefore are only correct if fundamental lighting principles have been given proper consideration. Reverting therefore to the six considerations set out in the beginning of this article their application to each particular sport must now be considered.

DOG TRACK AND SPEEDWAY LIGHTING.

Even intensity is required above the ground level as the illumination must not fall off when the dogs are clearing hurdles, and in the case of speedway tracks, the rider's helmet must be illuminated whether he is near the centre or at the edge of the track.

The number of fittings and poles must be kept to a minimum and in certain instances it is very desirable that the poles should be collapsible in order to cause no obstruction when the centre of the ground is used for football or other sports during the hours of daylight.

The spectacular effect of the racing is enhanced by confining the lighting closely to the track and this effect is emphasised by switching off all the stand lighting at the beginning of a race.

It has been found possible to illuminate dog tracks and speedway tracks satisfactorily by means of a single row of fittings to the design of which special attention has been given in order to ensure that the fittings themselves are inconspicuous and do not detract from the effectiveness of the lighted track.

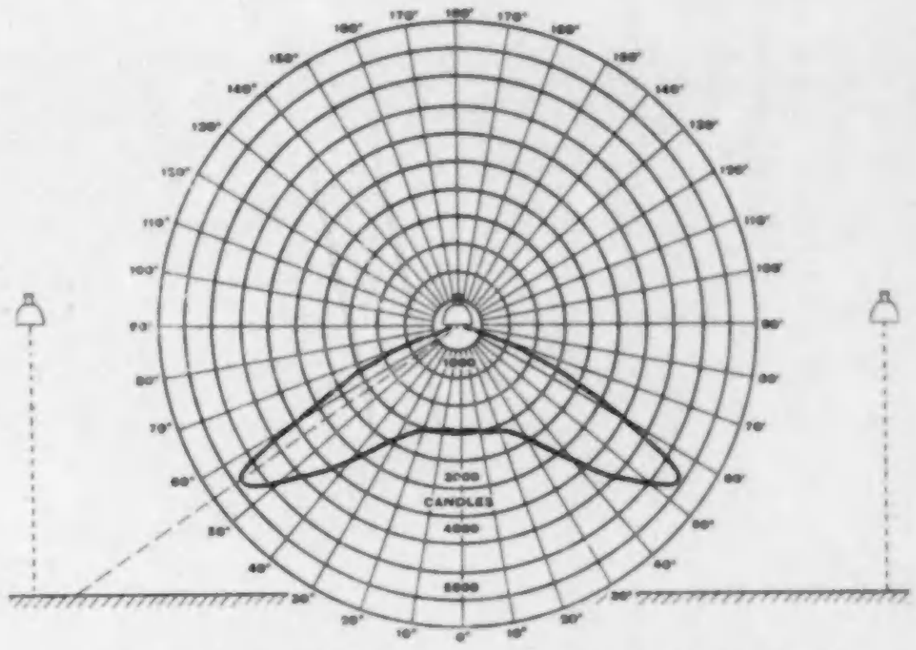


Fig. 4.—Polar curve of dog track lighting fitting.

DOG TRACK FITTING.

The fitting illustrated in figs. 2 and 3 has been developed for the illumination of dog tracks. It is made rectangular in shape so that each reflector illuminates a rectangular section of the track. It also embodies two bent mirror glass reflectors designed to give the required increase of candle power up and down the track, thereby affording an even intensity at a level of two or three feet above the track and at the same time, allowing a wide spacing height ratio to be used.

A polar curve of a fitting designed for a spacing equal to 1.6 times the mounting height is given in figure 4 from which it may be seen that there is a magnification of $2\frac{1}{2}$ with a maximum candle power at 55° from the vertical axis. It will be seen that with a spacing of 1.6 to 1 the peak of each fitting is directed to a point approximately beneath the adjacent fitting on each side, and though at first sight the overlapping of the beams to this extent may appear unnecessary, there are two reasons why a greater spacing ratio is not used. Though the actual measured intensity on the track may not vary, it is almost inevitable if the spacing of the fittings is too great, that there would be an appearance of bright patches, which are caused by specular reflections off the grass. It is a curious fact that these bright patches occur between the fittings, *i.e.*, at mid-span. The second advantage of completely overlapping the beams is that the failure of a single lamp may occur without interfering with the course of a race and without the spectators being aware of the fact.

Each alternate fitting can, if desired, be switched off between the races and it is of interest that when

this is done, the shadows on the track appear to be under the fittings which are in use and not under those which have been switched off.

If a spacing height ratio of 2 to 1 is required, the fitting is designed to have a peak angle at approximately 60° in order to retain the desired amount of overlapping of beams.

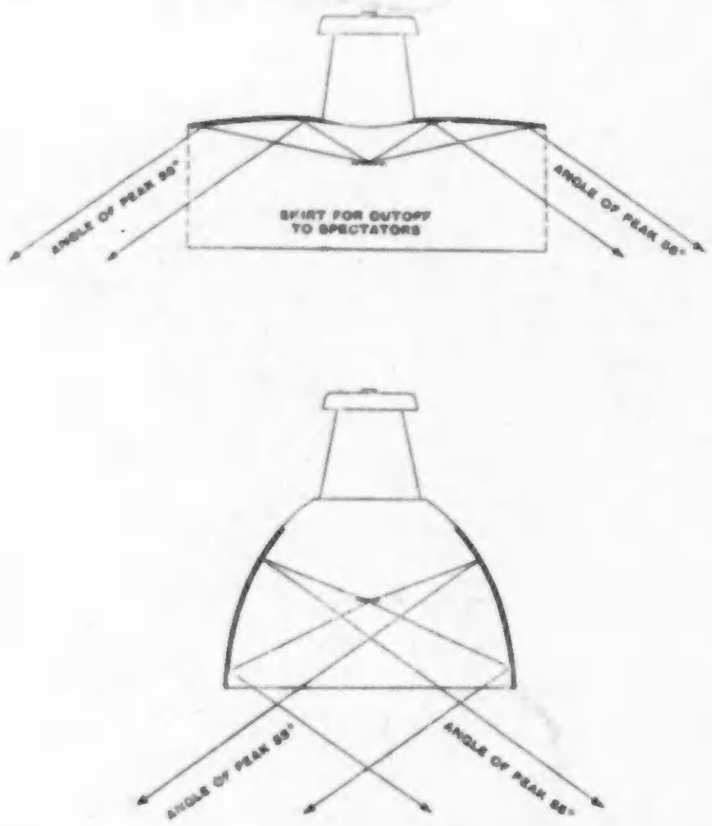


Fig. 5.—Illustrating the principle of (above) the open and (below) crossover fittings.

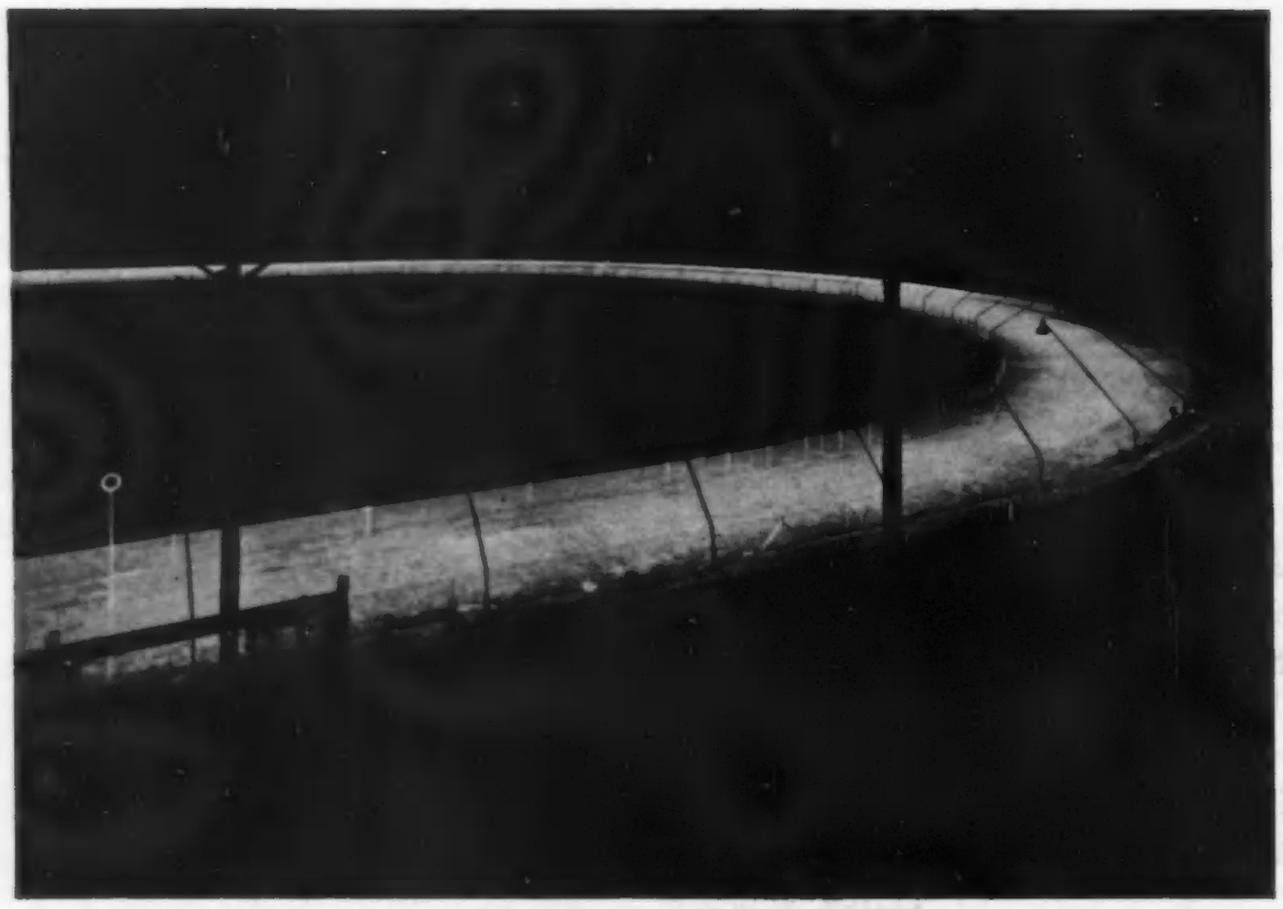


Fig. 6.—Night illumination of Stamford Bridge greyhound racing track.

In designing the mirror glass reflectors to produce the required polar curve, the cross-over principle illustrated in fig. 5 has been chosen because it results in a more compact fitting and also because the lamp filament can be arranged above the lower edge of the reflectors. This arrangement is impossible if the "open" type of reflector illustrated in figure 5 is used. Further, the cross over system permits the narrow side cut-off to be provided without the use of side fins which are objectionable because they are only fully effective when the observer is directly opposite the fitting and are partly inoperative when the fitting is viewed obliquely. In the case of the fitting illustrated, it will be seen that the lower edges of all four sides have been kept in one horizontal plane.

In order to produce a particularly sharp cut-off across the track at the desired angle, at the same time preventing skirt glare, the lower part of each side of the reflector is finished matt black.

A night view of the Stamford Bridge Track illuminated by this type of reflector is shown in figure 6 and attention is drawn to the fact that the fittings themselves are inconspicuous; the evenness of the lighting at the level of the top of the inner fence should also be noted.

This installation provides an instance where it was essential that a clear field of view should be left for spectators of daylight football matches and figures 2 and 3 illustrate the special type of collapsible lamp standards used. The standards can easily be placed in either of the positions shown by one man. As will be seen, the standards in the "down" position lie close behind the wire fence and the fittings are thus protected from mechanical damage.

SPEEDWAY FITTING.

The requirements for speedway lighting are similar in character to those for dog track lighting, but as the track is considerably wider, especially at the ends, a development of the dog track fitting is used, in which a third mirror glass reflector directs a beam of light straight across the track. Shadows cast by riders are a source of danger as they have been known to cause errors of judgment in riding and the three-directional effect produced by this modification in the fitting not only minimises these dangers but avoids the use of a multiplicity of fittings.

A night view of a speedway track illuminated with a single line of three-way fittings spaced 30 feet apart is shown in figure 7. The lighting of the widest part of the bends is augmented by the use of a single floodlight at each end of the track mounted on the upright of one of the standards, the object being to provide light on the inside of the riders so that their colours can be followed from any point of the ground. A special point is that this

inside lighting is provided without the use of poles on the inside of the track where they might be a source of danger to riders.

In the case of the track illustrated, where a greyhound track is arranged outside the speedway, rotating bracket arms are used and the single lighting installation serves the dual purpose of lighting for both tracks. Apart from the obvious reduction obtained in installation costs, the added obstruction of a second series of lighting fittings and standards is avoided.

Since the greyhound track is narrower than the dirt track, it is of course impossible to confine the light as closely to the greyhound track as is the case in a normal installation. To overcome this difficulty the fittings themselves can be rotated when the lighting is changed over from one track to the other and in this way the unwanted light is directed away from the spectators. Figure 8 shows the lighting of the greyhound track under these conditions.

Fig. 7.—Dual purpose lighting installation at Harringay where a speedway track is situated inside a greyhound racing track. View shows lighting of the speedway.

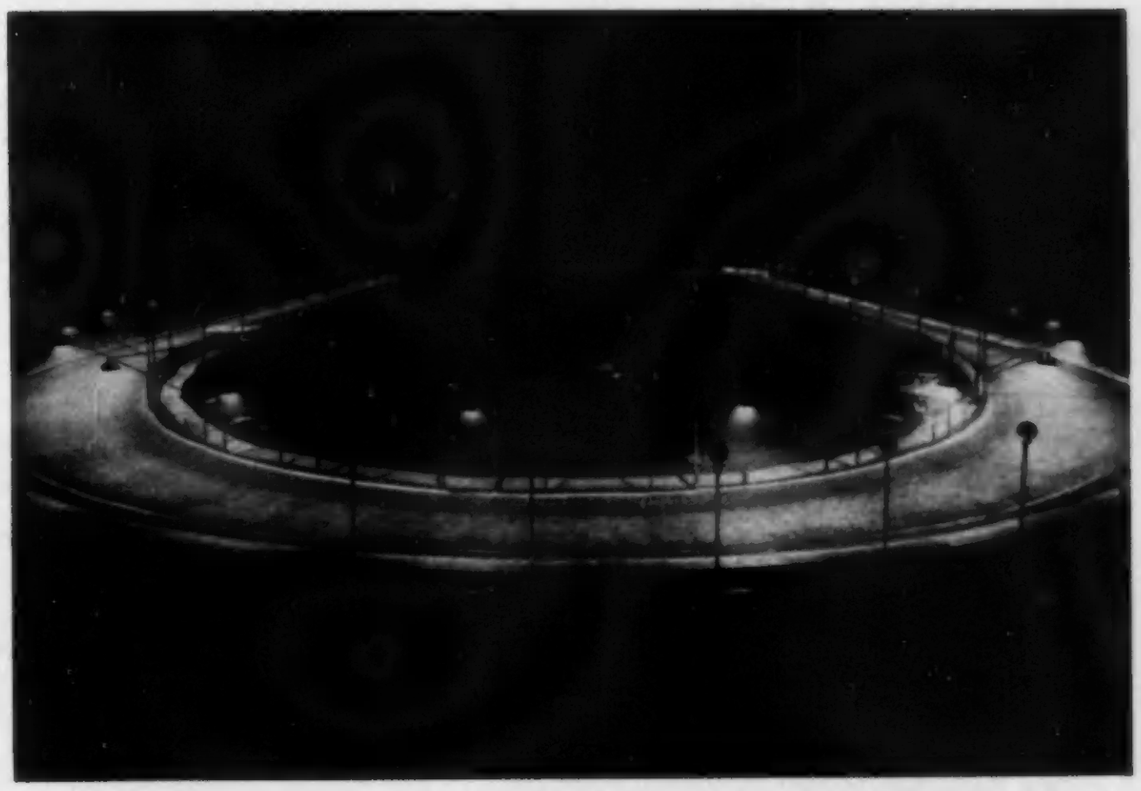


Fig. 8.—Lighting brackets have been swung round from position shown in fig. 7, and now illuminate greyhound track.

HORSE RACING.

Although horse racing at night has not yet become popular in this country, it may be stated with confidence that the three-way fitting used for speedway racing could be employed and would form a practical method of lighting.

BOXING.

Large crowds are always attracted by a big boxing match, and the largest sports stadiums are quite frequently filled to capacity by a popular fight. From the spectators point of view it is of paramount importance that every movement can be followed closely, those at a distance from the ring, who form the large majority, watching the fight with the aid of field glasses. Usually a very high intensity is provided varying between 100 and 300 foot candles, while for the supporting bouts it is usual to use only a proportion of the full installation, thus calling special attention to the main event on the programme.

It is particularly necessary to confine the lighting to the ring itself, firstly because the spectators are anxious to see the ring and the ring only, and secondly, because the ringside spectators themselves would strongly object to being included in the actual glare of the lighting.

A further requirement which is seldom appreciated is that purely vertical lighting must be avoided and a system used which gives the highest possible intensities on the vertical plane. It is one of the chief difficulties in the lighting of a boxing ring to provide this horizontal lighting, and at the same time confine the lighting to the ring itself.

The best compromise is arrived at by the use of concentrating fittings spaced close together over the whole ring, the outside fittings being directed across the ring and only those near the centre being directed vertically downwards. The height of the fittings above the ring is kept to a minimum and is controlled by the line of sight of the most distant spectators.

Fig. 9 illustrates the arrangement which it is suggested provides the most successful solution to the problem and makes clear the difficulty of providing the necessary side lighting without causing glare in the eyes of ringside spectators.

These remarks apply to both indoor and outdoor boxing where the attraction of the public is of first importance. For amateur boxing matches and

general training, the problem naturally becomes a comparatively simple one.

It should perhaps be mentioned that it is a common requirement that the lighting installation for

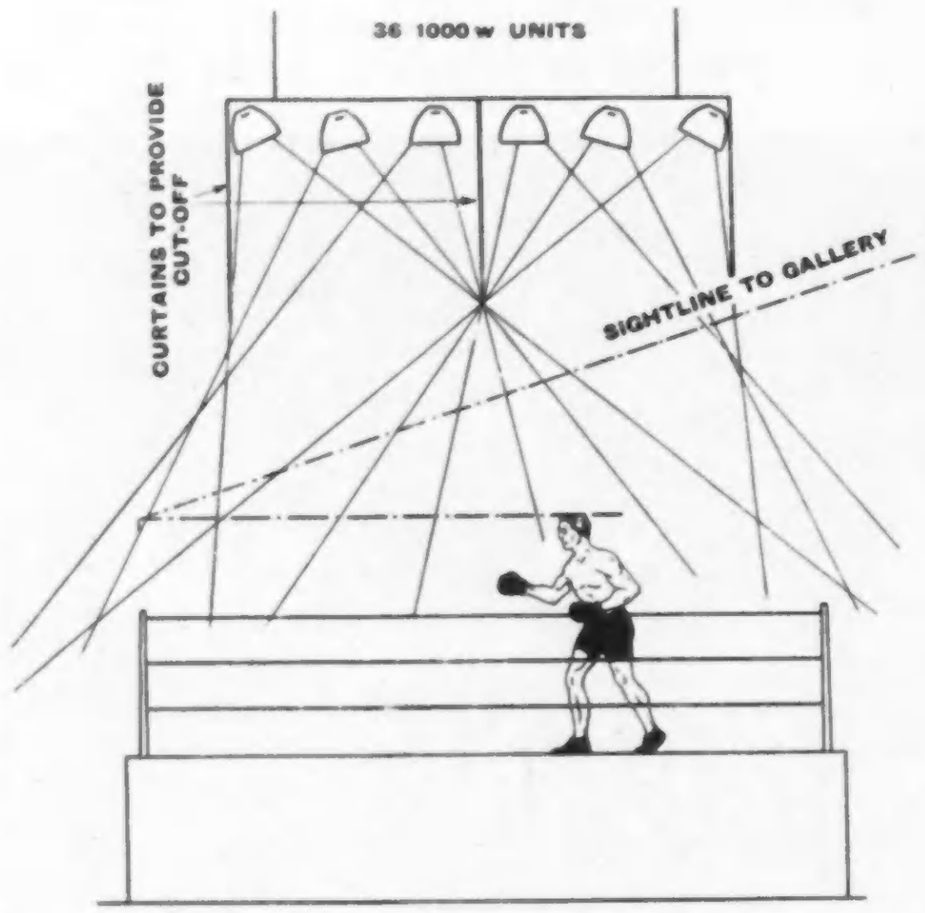


Fig. 9.—Diagrammatic representation of correct lighting of a boxing ring.

boxing should be of a temporary nature, capable of being stored away and fitted up as required.

FOOTBALL.

Owing to the attitude of the Football Association to the question of "floodlight" football, there has been very little development in this direction in this country so far as actual play is concerned, but floodlighting to allow evening training and practice out of doors is a thoroughly practical proposition which has not yet received the attention it deserves.

Of the lighting systems which have been used for the floodlighting of football grounds, there is little doubt that the most suitable and the one most likely to be used for future installations consists of four high towers, one at each corner of the ground, each carrying a battery of 30 or 40 floodlights of 1,000 watts each.

An overhead system using span wires carried across the ground has been tried, but a great objection is that the fittings cannot be suspended rigidly and the continual movement is a source of considerable annoyance. In addition, the system is very costly, maintenance is difficult and the appearance of the installation in the daytime is unsightly.

A third system which has been used with more success consists of floodlights arranged on each side of the ground at a height of 40 to 60 feet. A typical installation would consist of four masts on each side of the ground each supporting 8 to 12 floodlights arranged one above the other. A disadvantage is the comparatively large amount of glare associated with it, especially so far as spectators are concerned, while it is not practicable to increase the number of units sufficiently to give a really first class installation.

With the floodlighting installation from the four corners of the ground, the towers should be at least 120 feet high to ensure that the light sources do not come within the line of vision.

The initial training and focussing of the floodlights can be a very laborious process and the success of the installation depends upon the accuracy with which this is done. Each floodlight is focussed accurately for minimum divergence and should be directed to a certain point on the ground according to a carefully pre-arranged plan. It is important that the floodlights should have well

Fig. 10.—Lighting of squash racquet courts at the Badminton Club, Piccadilly, London.

designed and easily operated focussing devices and it is essential that they should be provided with accurate pre-set devices so that when they have once been trained they can be cleaned at any time and accurately re-set.

PRACTICE GROUNDS.

For the lighting of practice grounds an inexpensive system can usually be installed allowing clubs to provide their members with facilities for training in the evening during the football season and artificial illumination for this purpose is likely to be increasingly popular during the coming winter. The installation can consist of say five 1,000 watt floodlights and if the positions are carefully chosen, a considerable area may be made available for training.

SQUASH RACKETS, RACKETS AND FIVES.

These games, which are allied so far as lighting is concerned, are fast becoming popular as forms of winter exercise, and only a small outlay is required to provide a first class installation.

It is necessary to provide a high intensity in order that the small, fast moving ball may be followed and it has to be remembered that the intensity must be even at all levels in the court. Further, owing to the high wattage lamps which are used, there is considerable danger of glare in the eyes of players if precautions are not taken to avoid it.

The fittings are closely spaced to give the required evenness of lighting and it is usual to provide six points for each court. The fittings which are most likely to cause glare are the two nearest to the front wall since the players are normally facing in that direction. Angle fittings are therefore used in these positions, which, besides shielding the actual lamps from the players, have the additional advantage that they provide special illumination for the front wall. The fittings in the centre and at the back of the court are placed almost directly above the players and are therefore not so likely to cause glare though they should always be fitted

Fig. 12.—One of the lighting fittings used in the installation shown in fig. 11.

with obscured type lamps as a momentary glance at the bare filament of the 300 watt or 500 watt lamps used may give rise to a retained image which would make the player lose sight of the ball.

Fig. 10 is an illustration by artificial light of an installation at the Squash Courts at the Badminton Club, Piccadilly.

Fig. 11.—Badminton court at Kensington Baths, London, illuminated by specially designed fittings.

BADMINTON.

One of the great advantages of Badminton is that a specially built court is not necessary and nearly every gymnasium or hall can be used for the purpose.

The accepted form of lighting, which is used for first class tournaments and by hundreds of small clubs, consists of two fittings arranged one at each end of the net at a height of some nine feet above the ground. Each fitting is usually equipped with three 200 watt lamps and fitted with a distributing type of glass.

It is essential that the fittings should be designed to give light upwards as well as downwards, owing to the fact that the play is so largely overhead and light is required under the shuttle. It is for this reason also that the mounting height of the fittings should not be excessive.

In large halls a number of Badminton courts are frequently arranged side by side and when this is the case, double sided fittings are employed for the central positions and the total number

of fittings required is one more than the number of courts in use.

The two fittings required for a court can easily be made portable and this is often an advantage in halls which are used for various purposes. A typical installation is shown in fig. 11, and one of the fittings in fig. 12.

LAWN TENNIS.

In this country while outdoor lawn tennis is seldom played after dark, indoor tennis, artificially lighted is fairly popular. It cannot be said to be as common an indoor sport as Badminton perhaps because the number of halls in which it is possible to play are more limited.

In tropical countries where the time of sunset does not vary greatly throughout the year, outdoor tennis under artificial lighting is popular as it allows tennis to be played in the cool of the evening after the sun has gone down.

Probably the most suitable equipment for tennis court lighting, whether indoors or outdoors, consists of an installation of six 500 watt angle reflectors spaced evenly along each side of the court at a height of about 15 to 20 feet. In this position they are comparatively free from danger of damage and with properly designed reflectors, glare is practically eliminated. Fig. 13 shows an installation employing specially designed reflectors of this type.

Overhead lighting is sometimes successfully used both for indoor and outdoor courts, while for indoor courts, indirect lighting can be very effective, though somewhat heavy in current consumption.

It is not possible to concentrate the light sources near the ends of the net as in the case of Badminton, firstly, because the court is considerably greater in size and secondly because the ball must be evenly illuminated from all directions. The Badminton shuttle is easily visible even with the source of light partially behind it owing to the transparency of the shuttle feathers.

CRICKET.

During the winter, indoor practice nets and cricket schools provide the professional with employment and the keen club player with practice and coaching.

The method of lighting found to be most suitable consists of dispersive reflectors mounted directly over the centre of each net and closely spaced so as to ensure even illumination of the ball as it travels through the air. In addition, a white screen behind the bowler is illuminated to an appropriate intensity and serves the same purpose as the sight screen on the cricket field. A net stretched beneath the roof under the lighting fittings affords protection for the latter.

Figure 14 shows the manner in which a special problem has been overcome in the case of the Alan Fairfax School of Cricket at Thames House, Millbank. As will be seen, the large steam pipe which runs down the centre of one of the two pitches renders it impossible to use a central line of fittings. The symmetrical arrangement finally decided upon however, provides excellent lighting for the two pitches.

Fig. 13.—Tennis court lighting by special angle reflectors.

GOLF.

Golf under artificial illumination is practically confined to practice nets indoors, and to putting and miniature courses.

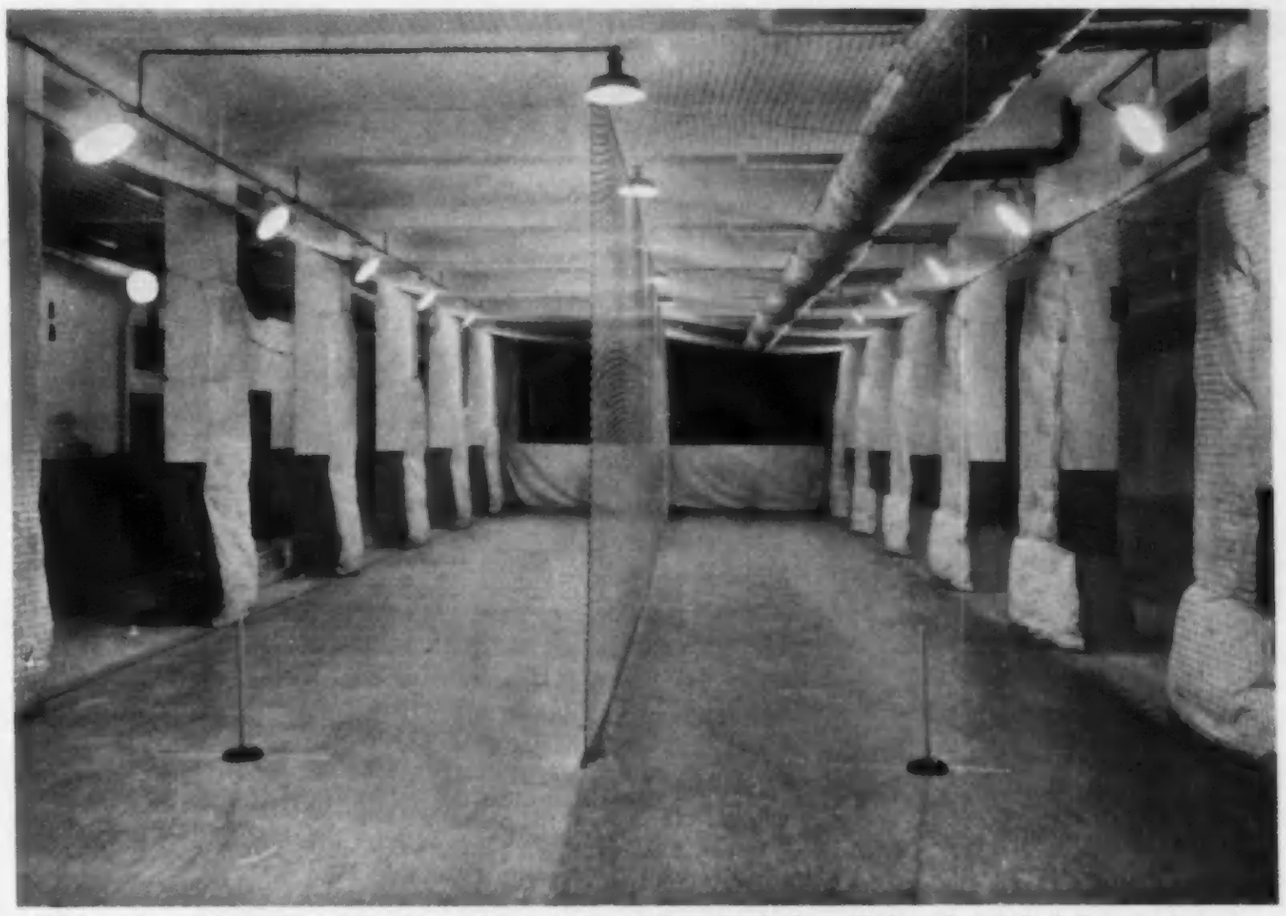


Fig. 14.—Lighting of the nets at the Alan Fairfax School of Cricket, where the 1934 Australian Team practiced on arrival in this country.

Fig. 15.—Illumination of miniature golf course at Harwich.

The lighting requirements are of a standard nature and so far as outdoor putting courses are concerned, a system of floodlights of large diameter and constructed of vitreous enamelled steel is both adequate and inexpensive. Typical installations are shown in figs. 15 and 16.

BOWLS, CURLING RINKS, ICE HOCKEY.

Successful installations of artificial lighting of each of these sports exist, the nature of the equipment being similar to that used for miniature golf or putting courses.

SHOOTING GALLERIES.

The lighting of indoor miniature rifle ranges presents points of special interest. Usually the light is confined to the end of the gallery and the side walls are of black non-reflecting material. It is a simple matter to direct any required amount of light on to the targets and at the same time screen the sources of light from the marksmen. The problem, however, does not end here, and it has been found that good results are only obtained if the targets are fixed to a light coloured background in the manner shown in figure 17.

If the targets have a black background it has been found that though it is easier to see the targets, it is less easy to see the actual bulls and additional eye strain occurs which results occasionally in a complete momentary black-out, an effect which is most noticeable when aperture sights are being used.

BILLIARDS.

For the lighting of billiard tables in billiard saloons, direct lighting with two or three shaded fittings is satisfactory, all that is required being a good even intensity with a cut-off a little above the edge of the table.

Indirect lighting has been used in large billiard saloons but the system is not very suitable as the attention tends to be attracted more by the brightly illuminated ceiling than by the actual tables.

In considering the lighting for a table which is to be used for a professional match, it is probable that a standard arrangement of six lights over the table will be preferred. Details such as the positions of the reflections of light sources on the balls are of importance to first class players and it is advantageous that for match play a standard arrangement should be decided upon and always used.

SWIMMING.

The well-equipped swimming pool and indoor swimming bath is an institution which meets a real public need. The popularity of almost every new pool which is opened is evidence of the great amount of public support which seems to be available for schemes of this sort.

Ambitious projects have been carried through with great success to which the varied forms of illumination introduced have made a marked contribution.

Swimming is perhaps the only sport in which

Fig. 16.—Putting green at Largs, Scotland, illuminated at night.

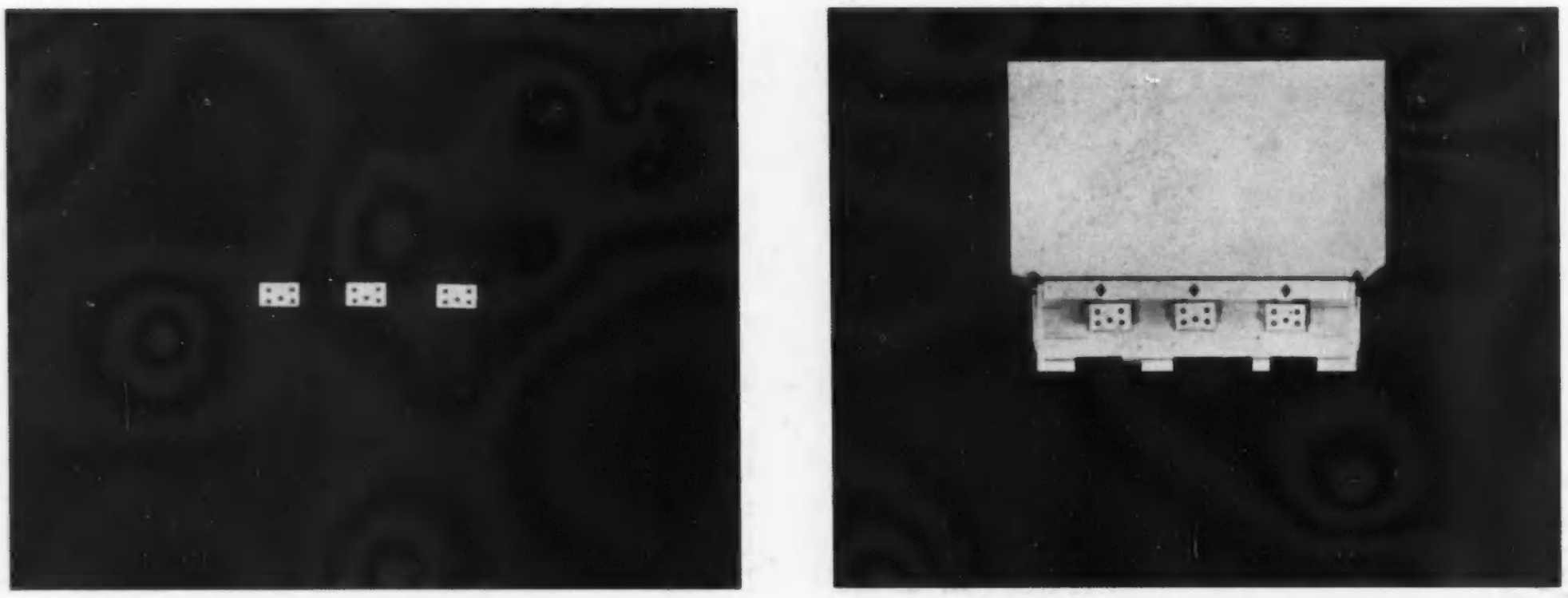


Fig. 17.—Comparison of visibility of bulls on targets (left) with dark background and (right) light coloured background.

many people can take part at once. In addition, spectators are increasingly attracted by swimming galas, diving displays and the like.

Underwater lighting is particularly effective as a spectacle and has the advantage that the movements of swimmers in the water may be closely followed by spectators. Many of the spectators attending a first class swimming event are themselves keen swimmers and are as anxious to watch the swimmers' movements as are the spectators, for example, of a lawn tennis match to study the strokes of the players. A further point in favour of underwater lighting is that there is little danger of the occurrence of the type of fatality caused by a swimmer getting into difficulty unnoticed by the authorities. It is the business of the attendant to keep a watchful eye on the bathers to prevent such accidents and his task is rendered the more easy when the bath is illuminated so that the whole of the bottom is visible.

The general arrangement of a typical underwater floodlighting unit is shown in figure 19 and a series of such units may be used either spaced regularly along each side of the bath, or, when the pool is of an irregular shape, arranged in batches illuminating particular areas, thereby producing particularly spectacular effects.

The underwater lighting unit comprises a skeleton floodlight which should be equipped with a 500 or 1,000 watt lamp. The porthole consists of a naval brass ring glazed with armour plate glass—a modern product of some interest owing to its very great mechanical strength and heat resisting quality. It may be mentioned that this glass is able to withstand such treatment as the pouring of molten lead on one side while the other side is in contact with cold water. The glass recommended for underwater lighting is ⅝in. thick, lead and rubber packing washers being used to ensure a watertight joint. If a regular spacing is used, this is usually between

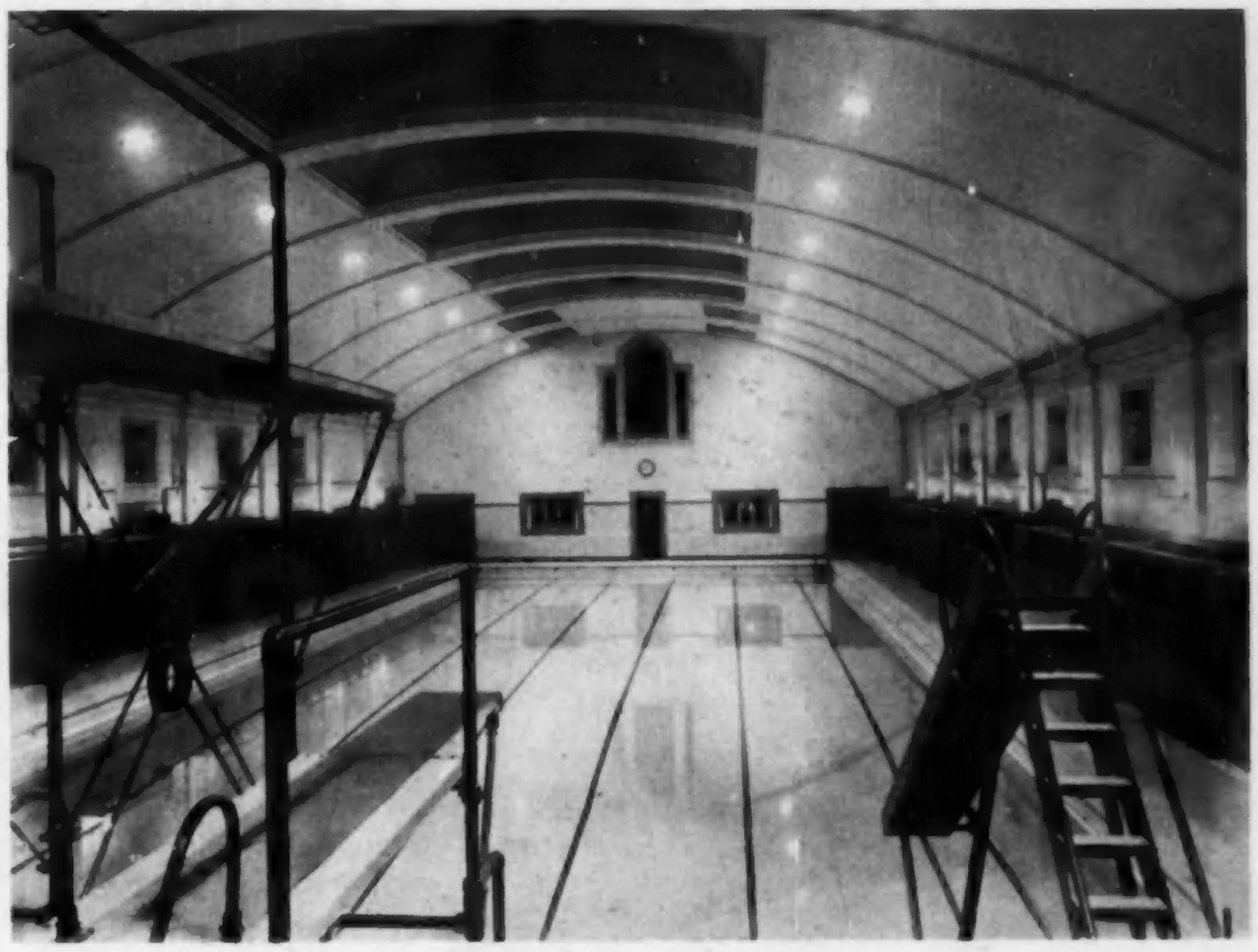


Fig. 18.—Typical indoor swimming bath lighting installation.

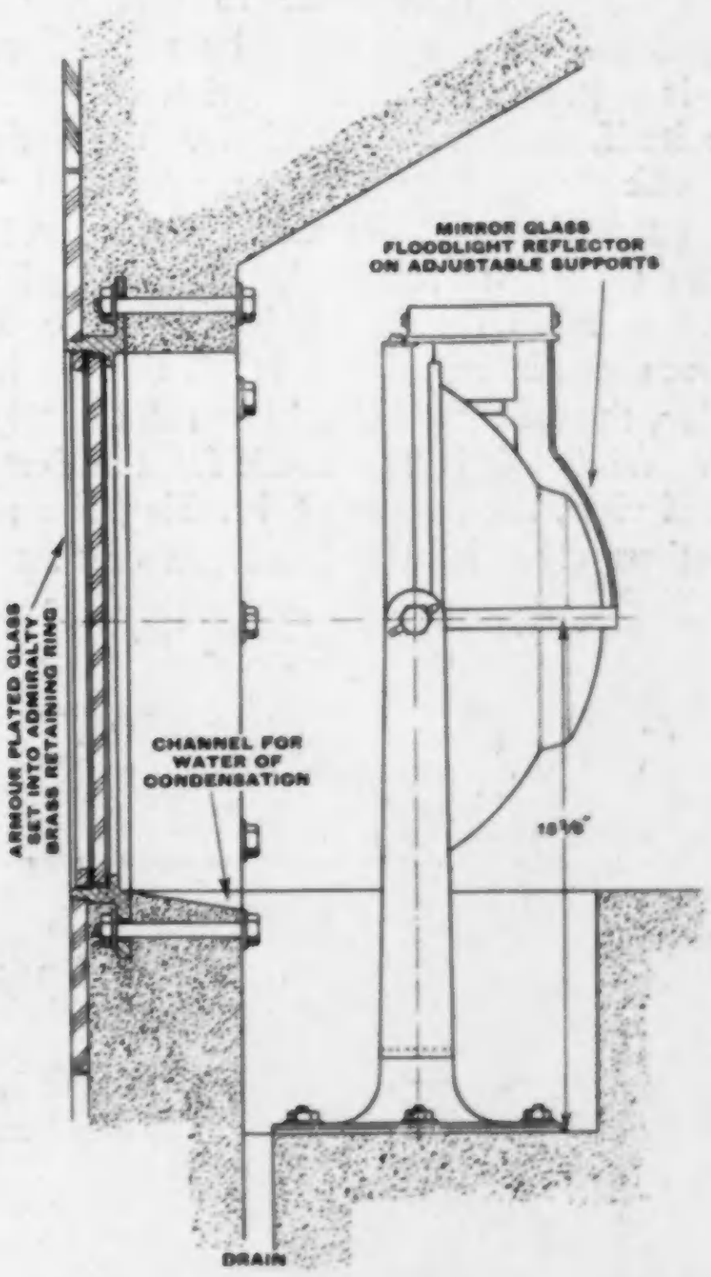


Fig. 19.—Diagram of underwater lighting fitting for swimming baths.

10 and 15 feet and it is convenient for servicing purposes to provide an underground passage-way giving easy access to all the units.

Colour screens can be introduced in front of the floodlighting units in order to give any desired coloured effects, but it must be remembered that there is a good deal of absorption of light in the water itself, and in the opinion of the author, the most effective schemes are produced by white light only, the full light value of the underwater lighting thus being retained. The use of electric discharge tubes for coloured underwater lighting has been considered, but it is felt that to be fully effective, the tube itself should be run actually in the water. While this is practicable from an installation point of view, the danger of breaking the tube by the bathers using it as a hand rail or foot rest is considerable, and some form of protection would undoubtedly be necessary.

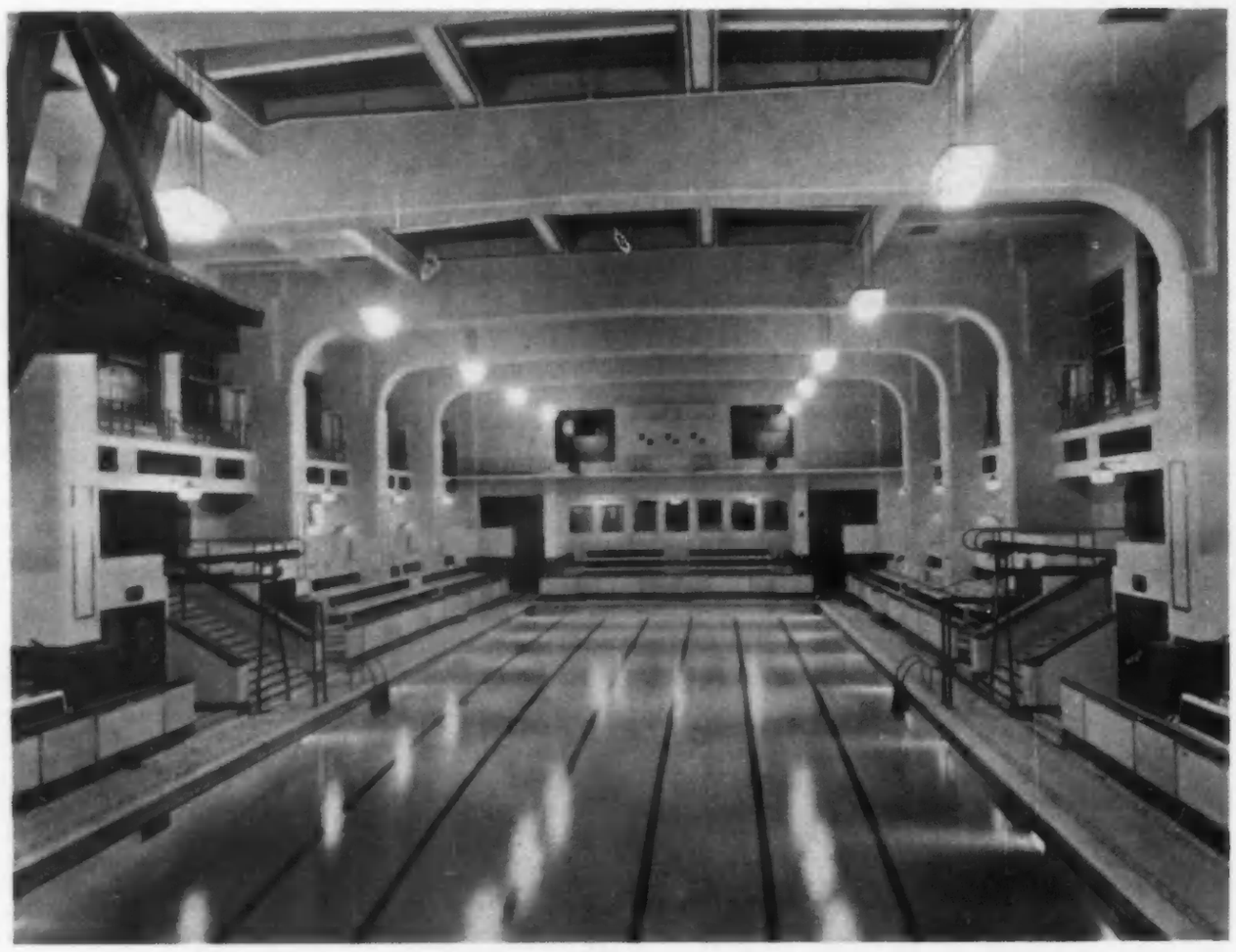


Fig. 20.—Combined overhead and underwater lighting at the Leyton baths.

Very beautiful and spectacular effects are obtained if the aerating cascades, which are part of the standard equipment of an outdoor swimming pool, are designed to include white or coloured lighting units or colour change effects introduced by means of flashers.

Interior overwater lighting of indoor baths has considerably developed, the modern swimming bath having a lighting scheme to harmonise with the architecture of the building. Figures 18 and 20 illustrate installations of this character. A good general intensity is provided to give the cheerful effect and general atmosphere of cleanliness which is so desirable.

Floodlighting of outdoor swimming pools is growing in popularity and can be used with or without underwater lighting. This lighting includes in many cases, the lighting of lawns or slopes surrounding the actual bathing pool, and installations of this kind are increasing in number throughout the country. The usual equipment consists of 500 or 1,000 watt floodlights which are mounted on steel or concrete columns at a height of 35 or 40 feet. In some cases, buildings or surrounding trees can conveniently be used for the support of the floodlights.

Amber or flame colour screens are sometimes used with this type of lighting and produce a warm tone which is psychologically effective. Bathing is also made possible after dark at some of the more popular natural bathing beaches by means of floodlighting and illuminated beaches are nowadays a special holiday attraction at the larger seaside resorts.

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